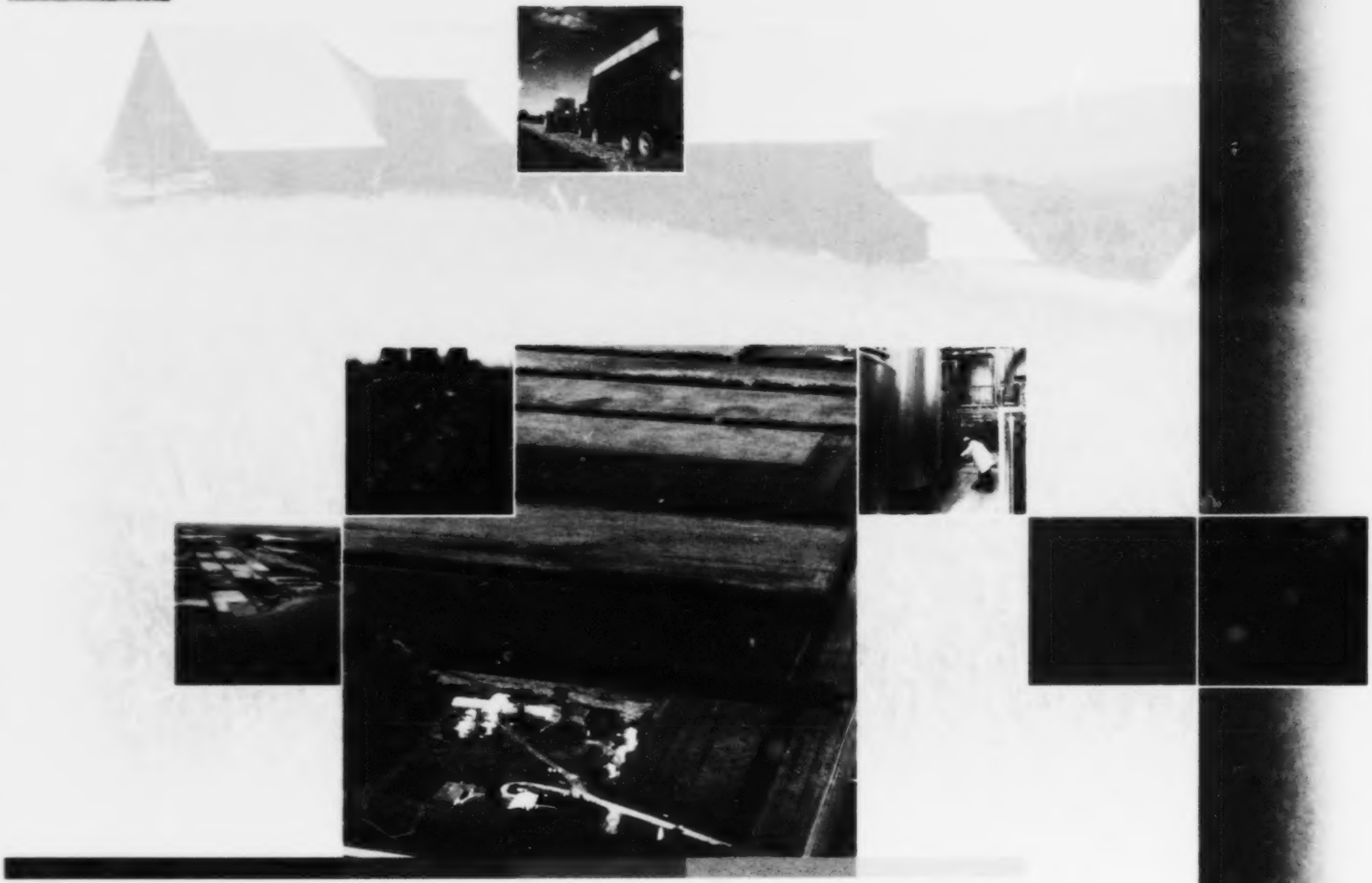
Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

Environmental Sustainability of Canadian Agriculture

Agri-Environmental Indicator Report Series

Report #2



Canada

© Her Majesty the Queen in Right of Canada, 2005

To obtain additional copies:
Publications Section
Agriculture and Agri-Food Canada
Sir John Carling Building
930 Carling Avenue
Ottawa, Ontario K1A 0C5
(613) 759-6626

This publication is also available electronically on the World Wide Web at the following address:
http://www.agr.gc.ca/env/naharp-pnarsa/index_e.php

Canadian Cataloguing in Publication Data

Main entry under title:
Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series – Report #2

Issued also in French under title:
L'agriculture écologiquement durable au Canada : Série sur les indicateurs agroenvironnementaux – Rapport N° 2

Cat. No. A22-201/2005E
ISBN 0-662-42205-8
AAFC No. 10081E

This report can be cited as follows:
Lefebvre, A., W. Eilers, et B. Chunn (eds.). 2005. *Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series – Report #2.* Agriculture and Agri-Food Canada, Ottawa, Ontario.

Each chapter can be cited as follows:
[Name(s) of chapter author(s)]. 2005. [Chapter heading]. Pages [. . .] – [. . .] in Lefebvre, A., W. Eilers, et B. Chunn (eds.). 2005. *Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series – Report #2.* Agriculture and Agri-Food Canada, Ottawa, Ontario.

Printed on recycled paper

106-02017/

Environmental Sustainability of Canadian Agriculture

Agri-Environmental Indicator Report Series
Report #2

A. Lefebvre, W. Eilers, and B. Chunn (editors)

Agriculture and Agri-Food Canada

2005

Contents

A Word from the Minister of Agriculture and Agri-Food Canada iii

Executive Summary iv

A) INTRODUCTION

1. Introduction 2
2. Assessing the Environmental Sustainability of Agriculture 7
3. Driving Forces Affecting the Environmental Sustainability of Agriculture 18
4. Overview of Agriculture in Canada 24
5. Linking Science to Policy 36

B) ENVIRONMENTAL FARM MANAGEMENT

6. Agriculture Land Use Change 42
7. Farm Environmental Management Practices 49
8. Soil Cover 61
9. Nitrogen Use Efficiency 69
10. Energy Use Efficiency 76
11. Water Use Efficiency: Irrigation 83
12. Integrated Pest Management 85

C) SOIL QUALITY

13. Soil Erosion 90
14. Soil Organic Carbon 108
15. Soil Salinity 114
16. Trace Elements 119

D) WATER QUALITY

17. Nitrogen 124

18. Phosphorus 131

19. Pesticides 136

20. Pathogens 138

E) AIR QUALITY

21. Greenhouse Gases 142

22. Ammonia 149

23. Particulate Matter 153

F) BIODIVERSITY

24. Wildlife Habitat on Farmland 158

25. Wildlife Damage to Crops and Livestock 165

26. Invasive Alien Species 168

27. Soil Biodiversity 171

G) FOOD AND BEVERAGE INDUSTRY

28. Energy Use and Greenhouse Gas Emission 176

29. Water Use and Effluent Generation 180

30. Organic Solid Residues and Packaging Wastes 184

H) NATIONAL AND REGIONAL SUMMARY

31. National and Regional Summary 190

I) ANNEXES

Glossary 206

Contributing Authors 212

Acknowledgements 215

Minister
of Agriculture and
Agri-Food

Ministre
de l'Agriculture et de
l'Agroalimentaire

Ottawa, Canada K1A 0C5

MESSAGE FROM THE MINISTER OF AGRICULTURE AND AGRI-FOOD

The environmental challenges of today in agriculture are many and complex. As a result, decision makers at all levels need reliable information to better understand and manage the links between human activity, the economy and the environment.

To better assess the impact of agricultural policies on the environment, in 1993 Agriculture and Agri-Food Canada began developing science-based environmental indicators for the agriculture and agri-food sector. As these tools have improved, so too has our ability to help guide and measure the environmental performance of the sector. In 2000, we published the first agri-environmental indicator report.

As Minister of Agriculture and Agri-Food Canada, I am pleased to present this second report on national agri-environmental indicators. This report provides an updated picture of the progress that Canadian agriculture has made in both conserving the natural resource base upon which it depends, as well as supporting surrounding natural ecosystems. It also informs us about more work that must be done. By doing this, the report can help us tackle the environmental challenges of our day—challenges that call upon us to find better ways to improve productivity and competitiveness, while ensuring that whatever we do sustains a healthy environment.

Agriculture and Agri-Food Canada will continue to work closely with producers and partners to generate this important information. In so doing, we will contribute to building the foundation of the environmental policies and programs of the future, and ensuring Canada's place as the world leader in environmentally responsible agriculture production.

Andy Mitchell

Canada

Executive Summary

CONTEXT

The agriculture and agri-food industry operates in close connection with the surrounding environment. Environmental sustainability—producing and processing food and fibre in a way that protects or enhances the natural resources which support production and is compatible with the surrounding natural systems—is therefore not a new concept for the sector. Producers have for a long time been adopting technologies, production strategies and beneficial management practices that improve their environmental performance.

In recent decades, globalization, market pressures and technological innovations have spurred Canadian agriculture to increase output and productivity. This has engendered structural changes in the industry, characterized by the adoption of new technologies and a gradual shift towards larger, more intensified operations. Social preferences of Canadians have also evolved, and concerns have been raised about the possible impact of food production on the environment—on soil, water and air quality, and biodiversity. Canadians have supported a growing array of domestic and international agreements, regulations and research programs designed to protect the environmental systems with which agriculture interacts. Agriculture today has to balance a wide range of continually evolving environmental demands and expectations. Achieving the goal of long-term environmental sustainability has become a more pressing challenge and one that involves increasingly complex issues.

Farmers, governments and other stakeholders in Canada's agricultural industry have become increasingly aware of the need to integrate environmental factors into their decision-making processes. Decision makers at all levels share a common need for objective information on the current environmental performance of the agricultural sector, to determine whether this performance is satisfactory and how it is likely to behave in response to the decisions they make.

AGRI-ENVIRONMENTAL INDICATORS

Agriculture and Agri-Food Canada has developed a set of agri-environmental indicators (AEIs) specific to the agriculture and agri-food sector to assess how well agriculture and agri-food systems manage and conserve natural resources and how compatible they are with the natural systems and processes in the broader environment. These AEIs are a practical means of assessing environmental sustainability by combining current scientific knowledge and understanding with available information on resources and agricultural practices. The intent is to provide an objective, science-based assessment of the overall environmental sustainability of agriculture. These agri-environmental indicators can then be used to:

- track progress and measure performance in achieving priority environmental objectives;
- draw public attention to important environmental issues;
- translate scientific knowledge and research results into a form that can be understood and used by citizens and decision makers; and
- educate students and citizens interested in understanding agri-environmental issues and their implications.

Agri-environmental indicators are calculated using mathematical models or formulas that integrate biophysical information (on soil, climate and landscape) with land use and farm management data generalized to portray certain environmental conditions in the landscape at a given time. They are primarily intended to provide information on a national, provincial and regional scale, in a manner that is both sensitive to regional variations in agriculture and consistent across Canada. However, to make national assessments, it is necessary to work at broad temporal and spatial scales and to use units that are usually not homogeneous in terms of either farm management practices or biophysical conditions. The aggregated result may therefore obscure local reality, and because of this the indicators cannot be interpreted as showing any specific on-site conditions such as at an individual farm.

A first set of AEI results was published in 2000 covering a 15-year period (1981 to 1996). Building on this initial work, and in light of current and future needs for this kind of information, AAFC established the National Agri-Environmental Health Analysis and Reporting Program (NAHARP) to strengthen its capacity to develop AEIs and tools to integrate them with policy development. This report, the second of the *Agri-Environmental Indicator Report Series*, can be viewed as an incremental step towards the objective of periodically reporting on the environmental sustainability of Canadian agriculture. The work on agri-environmental indicators involves a process of continuous improvement, and most of the indicators from the first report have been updated, extending the temporal coverage to 2001. Improvements have also been made to existing methodologies and datasets, which means that results and trends for these indicators have been re-assessed for the entire 20-year period covered (1981 to 2001). This second report also provides information on new indicators that are in various stages of development and are expected to generate results in the near future.

■ SUMMARY OF RESULTS

The AEIs included in this report focus on four key components of the environmental sustainability of primary agriculture: soil quality, water quality, air quality and biodiversity. The results reveal some consistent national trends, as well as considerable differences in various agri-environmental conditions across Canada. Overall, the results suggest that considerable progress has been achieved towards environmental sustainability, but that further expansion and intensification of cropping and livestock production has the potential to exacerbate the environmental risks unless appropriate actions are taken to manage them. The main AEI results for the period 1981 to 2001 can be summarized as follows:

- **Environmental farm management:** This component consists of five indicators, including three that currently provide national coverage (Soil Cover, Residual Soil Nitrogen and Energy Use Efficiency). Results are mixed, with soil cover showing overall improvement, whereas nitrogen use efficiency and energy use efficiency have declined. The two other indicators are still under development (Water Use Efficiency: Irrigation and Integrated Pest Management).
- **Soil quality:** There are five soil quality indicators with results, including separate indicators for assessing the risk of soil erosion by water, wind and tillage. The Soil Organic Carbon Change Indicator tracks changes in soil carbon content, and estimates CO_2 sequestration in agricultural soils. The Risk of Soil Salinization Indicator is designed to assess the change in soil salinity on the Prairies. All five indicators showed improvement, with a majority of land in the very low risk classes for erosion and salinity and most land falling into the increasing classes for soil organic carbon change. An additional indicator, the Risk of Soil Contamination by Trace Elements, is being developed to gain a better understanding of how agricultural management practices can affect the levels of trace elements in the soil and change their bioavailability.
- **Water quality:** On the water quality front, two separate indicators were used to assess the Risk of Water Contamination by Nitrogen and by Phosphorus, taking into account changes in land use (e.g. shifts in crop area) and management practices (e.g. fertilizer inputs). Mixed results were obtained for these two indicators. While close to two-thirds of the land shows a low or very low risk of water contamination by nitrogen, the 20-year trend is worsening. By contrast, the trend for the risk of water contamination by phosphorus (Quebec only) is improving, although only a third of farmland is in the lowest risk classes. Two additional indicators, dealing with pesticides and pathogens, are still under development.
- **Air quality:** One air quality indicator is currently available—the Agricultural Greenhouse Gas Budget estimates greenhouse gas (nitrous oxide, methane and carbon dioxide) emissions from agricultural sources. The indicator shows a positive

Table 1: Summary of indicator results

Issue	Indicator Results (2001 National Snapshot)	Trend (1981-2001)
Environmental Farm Management		
Soil Cover	32% of *cropland* in the high and very high soil cover classes (300 soil cover days or more)	Improving
Nitrogen Use Efficiency	28% of cropland in the low or very low classes for Residual Soil Nitrogen	Worsening
Energy Use Efficiency	3% decline in the energy use efficiency ratio	Worsening
Soil Quality		
Water Erosion	86% of cropland in the very low class for the Risk of Water Erosion Indicator	Improving
Wind Erosion	86% of cropland (Prairies) in the very low risk class for the Risk of Wind Erosion Indicator	Improving
Tillage Erosion	50% of cropland in the very low risk class for the Risk of Tillage Erosion Indicator	Improving
Soil Organic Carbon	31% of cropland in the large increase class for the Soil Organic Carbon Change Indicator	Improving
Soil Salinization	70% of agricultural and adjacent land (Prairies) in the very low risk class for the Risk of Soil Salinization Indicator	Improving
Water Quality		
Nitrogen	65% of farmland in the low or very low risk classes for the Risk of Water Contamination by Nitrogen Indicator	Worsening
Phosphorus	29% of agricultural land (Quebec) in the low or very low risk classes for the Risk of Water Contamination by Phosphorus Indicator	Improving
Air Quality		
Greenhouse Gases	4.4% (2.5 Mt CO_{2eq}) reduction in the Agricultural GHG Budget (net emissions)	Improving
Biodiversity		
Wildlife Habitat on Farmland	19% of farmland showing a moderate or large increase in the Wildlife Habitat Capacity Indicator	Worsening

national trend, with a 4% reduction in net GHG emissions during the period under review. This trend is largely attributable to an increase in soil carbon sequestration, which compensated for a rise in nitrous oxide and methane emissions. Work is continuing on the development of indicators for measuring agricultural emissions of ammonia and particulate matter.

- **Biodiversity:** Biodiversity is assessed using the Indicator of Wildlife Habitat on Farmland, which provides insight into trends in wildlife habitat availability on Canadian farms. Somewhat negative results were obtained for this indicator, with more farmland showing a decreasing trend in habitat capacity than a rising trend. Several other indicators are currently under development: risk of wildlife damage; invasive alien species; and soil biodiversity.
- **Food and Beverage Industry:** AAFC's science-based indicator approach is being expanded to include eco-efficiency indicators for the food and beverage industry as well. These indicators, still under development, will cover the following environmental issues: energy use and greenhouse gas emissions; water use and effluent generation; and organic solid residues and packaging wastes.

Introduction

A

1. Introduction

AUTHOR:
A. Lefebvre

ADAPTED FROM:
McRae, 2000

■ ENVIRONMENTAL SUSTAINABILITY: A PRIORITY IN AGRICULTURE

Sustainable development is a concept that integrates environmental, economic and social interests in a way that allows today's needs to be met without compromising the ability of future generations to meet their own needs. In the agriculture and agri-food sector, sustainable development calls for ways of producing and processing food and fibre that protect or enhance the natural resources which support agricultural production, are compatible with surrounding natural systems and processes, contribute to the economic and social well-being of all citizens, ensure a safe and high-quality supply of agricultural products and safeguard the livelihood and well-being of agricultural and agri-food businesses, workers and their families (Agriculture and Agri-Food Canada 2003). This report focuses on *environmental sustainability* which is a key aspect of sustainable development in agriculture.

The agriculture and agri-food industry has a close connection with the environment, and environmental issues are not new to the sector. Canadians generally appreciate the environmental benefits that agriculture provides, including *wildlife habitat*, beautiful landscapes and natural processes such as *nutrient* cycling, and water storage and filtering. In recent decades, however, Canada's agricultural industry has seen significant changes, with the adoption of new technologies and a gradual shift towards larger, more intensified operations, in order to meet the growing global demand for agricultural products and to increase the country's share of global markets. These changes have raised questions about the implications of expanded production for the long-term sustainability of cropping practices and about the potential for environmental costs, such as declining water quality, loss of wildlife habitat, reduced biodiversity and *greenhouse gas* emissions. In light of the growing concerns, all sectors of agricultural production and processing are being urged to maintain acceptable levels of environmental stewardship. In some cases, heightened public concern now poses a direct constraint to agricultural growth. Furthermore, since globalization of markets has exposed Canadian agricultural products to greater numbers of consumers, these same concerns are expected to increasingly affect the sector's ability to retain and compete for international markets.

Consequently, agriculture today must balance a wide and continually evolving array of demands and environmental challenges. Governments, farmers and other stakeholders are working together to promote research, programming and related actions to address environmental concerns. The initial focus on conserving the natural resource base upon which agriculture depends—particularly soil, water and genetic resources for crops and livestock—has broadened to include other priority areas such as nutrient surpluses, the entry of pesticides and pathogens into water, the loss of *soil organic matter*, the release of *particulate matter*, odours and greenhouse gases, wildlife habitat availability and conservation of species at risk. Achieving the goal of long-term environmental sustainability in the agriculture and agri-food sector has become a more pressing challenge and one that involves increasingly complex issues.

■ INFORMATION FOR DECISION-MAKING: THE ROLE OF INDICATORS

The individual decisions of Canada's agricultural producers and processors have a direct influence on environmental sustainability. These decisions are influenced by a variety of factors and stakeholders beyond the farm gate. Governments influence decisions through the development of agricultural policies and programs, researchers develop new technologies for improved productivity and sustainability, and consumers influence the marketplace through their purchasing choices. Farmers, governments, researchers, environmentalists, processors and consumers are all concerned about ensuring the sustainability of Canada's agriculture industry and each of these different groups can influence the outcome of this undertaking in unique ways. However, they all share a common need for environmental information.

Decision makers at all levels need objective and reliable information on the current and expected future evolution of environmental performance in the agricultural sector. They need to know whether the current performance is satisfactory and how it is likely to behave in response to the decisions they make. If given this type of information, decision makers are likely to have a better understanding of the pressures they face and of the needs and opportunities to change the system.

Historically, governments and all sectors of economic activity have invested considerable resources to promote economic development and the use of systematic approaches and indicators for measuring economic performance. These approaches have, however, largely ignored environmental impacts, and the most commonly used economic indicators do not consider changes in the value of environmental assets and services. As a result, decision makers who rely solely on such indicators run the risk of achieving economic goals at the expense of environmental and other objectives. To address this problem, work is now under way to develop environmental indicators and tools for integrating these environmental indicators with economic and social information, in order to better understand and manage the links between human activity, the environment and the economy.

Environmental indicators are typically designed to measure and represent trends related to significant aspects of environmental sustainability such as the stresses that impact ecosystems, the response of ecosystems to change and societal actions to prevent or reduce these stresses. While indicators have often been described as "early warning signals" for emerging environmental concerns, they have also been criticized for failing to live up to this expectation. In reality, by the time environmental data are available and work has begun on a specific indicator, the environmental concern of interest is often no longer an "emerging" issue; instead it may have become a fairly high priority for the general public and policy makers alike (Bond et al. 2005). More appropriate expectations for environmental indicators would typically be along the lines of:

- tracking progress and measuring performance in achieving priority environmental objectives;
- drawing public attention to important environmental issues;
- translating scientific knowledge and research results into a form that can be understood and used by citizens and decision makers; and
- educating students and citizens interested in understanding environmental issues and their implications.

In 1993, in response to the need for agri-environmental information and to assess the impact of agricultural policies on the environment, Agriculture and Agri-Food Canada began to develop a set of science-based environmental indicators specific to the agriculture and agri-food sector. These *agri-environmental indicators* (AEIs) are designed to:

- inform agricultural and other decision makers about environmental performance in agriculture;
- determine how environmental conditions within agriculture are changing over time;
- provide information on the impact of the adoption of stewardship principles and on the use of environmentally sound practices;
- support the development of strategies and actions targeted at areas and resources that remain at environmental risk; and
- facilitate the environmental analysis of agricultural policies and programs and the monitoring of their performance.

A first set of AEI results was published in February 2000, in the report, *Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project* (McRae et al. 2000).

Building on this initial work, and in light of current and future needs for this kind of information, AAFC has established the National Agri-Environmental Health Analysis and Reporting Program (NAHARP). Its purpose is to strengthen departmental capacity to develop and continuously enhance AEIs and tools to integrate these indicators with policy development, using the following three complementary approaches:

1) Update the existing set of AEIs by enhancing methodologies and underlying data when appropriate and possible and develop new indicators to address key gaps in environmental information in the agricultural production and food processing sectors.

2) Improve the quality and reliability of tools that integrate agri-environmental indicators with economic information. While indicators provide a historical perspective on environmental performance, this integrated economic/environmental modelling provides an improved predictive capacity for testing different scenarios, for example, to better understand how changes to agricultural policies and programs may affect the sector's future environmental performance.

3) Develop the capacity to quantify the economic costs and benefits of environmental impacts in agriculture, for both farmers and society. There are no market mechanisms for determining the value of many impacts of agriculture on the environment, such as water quality, and wildlife habitat. By assigning an economic value to these issues, we will be able to perform quantitative trade-off analyses of environmental versus economic impacts.

Agriculture is linked to many global environmental issues, and agricultural products are a key element of global trade. Consequently, several international agencies are also working to develop and use environmental indicators for agriculture. The use of international indicators arises from the need to better understand the health of the global environment, to guide and evaluate international efforts to reduce environmental stresses and to help ensure that countries do not distort global markets and enhance their competitiveness through lax environmental standards or environmentally harmful subsidies. One international organization in particular, the Organisation for Economic Co-operation and Development (OECD) is co-ordinating efforts among its member countries to develop a set of agri-environmental indicators that are based on consistent and compatible methodologies. The OECD's indicators are being developed to:

- provide information on the current state and changes in environmental conditions within agriculture;
- better understand the linkages between the environmental impacts of agriculture, agricultural policy reform, trade liberalization and environmental measures along with the associated causes, and guide the responses to changes in environmental conditions;
- evaluate the effectiveness of policies addressing agri-environmental concerns and promoting *sustainable agriculture* (Organisation for Economic Co-operation and Development 2001).

The development of environmental indicators at the international level is especially challenging because of differences in environmental conditions, economic activity, national priorities and availability of data across countries. Through AAFC's work on agri-environmental indicators, Canada actively contributes to OECD efforts and benefits from the co-operation and exchange of results.

■ THE AGRI-ENVIRONMENTAL INDICATORS REPORT

Objectives of this report

This comprehensive report on national agri-environmental indicators is the second in what is envisioned to be periodic reporting on the environmental sustainability of Canadian agriculture. Its main objective is to communicate the results of work based on the concept of agri-environmental indicators and to attempt to answer some fundamental questions:

- To what extent do farmers and food processors use environmentally sound management practices?

- How are environmental conditions and trends within agriculture changing over time?
- What areas and resources remain at significant environmental risk?

As already indicated, the first report of the series was published in 2000. It presented results for a suite of 14 indicators, typically reporting trends for the period 1981 to 1996. This second report can be viewed as an intermediate step towards the objective of reporting on a comprehensive set of AEIs for Canada. Most of the indicators from the first report have been updated, extending the temporal coverage to 2001. Much of the text and reporting style for the indicators have been maintained or adapted from the first report, to ensure continuity. The present report also provides information on new AEIs that are in various stages of development.

The report is intended for all persons interested in the environmental sustainability of Canadian agriculture, particularly decision makers, keeping in mind that different stakeholders have different concerns and operate at different levels. For example, farmers decide which production strategies to use on their farms. Farm leaders and government policy makers interact with broader groups of producers, such as commodity groups or producer groups within particular regions, and deal with outside developments that affect agriculture (i.e. international environmental and trade agreements). And environmentalists are concerned with the developments within specific regions, specific environmental threats from agriculture or the health of specific components of the environment.

Often, these different stakeholders seek different policy outcomes and compete for attention on what can be a crowded and complex policy agenda. The objective of this report is neither to promote nor to reject various claims related to the environmental sustainability of the agriculture and agri-food sector. The intent is to provide an objective, science-based assessment of the overall environmental sustainability of agriculture, with a focus on farm management, soil, water and air quality, biodiversity and *eco-efficiency*.

Scope and limitations of this assessment

As a federal department, AAFC's goal is to provide a national assessment of the environmental performance of agriculture. Therefore, in the context of NAHARP, AEIs are primarily intended to provide information at a national, provincial and regional scale, in a manner that is both sensitive to regional variations in agriculture and consistent across Canada. However, to make national assessments, it is necessary to work at broad temporal and spatial scales and to use units that are usually not homogeneous in terms of either farm management practices or biophysical conditions. While we are confident that the current set of indicators provides a good preliminary assessment of the sector's performance in the pursuit of environmental sustainability, they are all subject to some level of uncertainty (see Chapter 2).

Indicators usually do not give a very precise picture of the farming or environmental conditions at specific locations. Accordingly, they are rarely applicable at the farm level, and this work is not intended as a guide to on-farm best management practices. AAFC, in partnership with the provinces and the agricultural industry, is involved in efforts to develop other tools that farmers can use to make informed on-farm land-use and management decisions, such as *Environmental Farm Planning*. Nonetheless, farmers should find this report useful as an introduction to environmentally sustainable agriculture and it may alert them to environmental conditions that pertain to their region. We encourage all users to exercise caution in interpreting and using this report.

Reading this report

The report is divided into eight parts:

- Section A gives the background of the study, including the general concepts, principles and approaches used to produce the indicators, and an overview of agriculture in Canada and of the driving forces that affect environmental trends in agriculture. The chapters in this section will help the reader to better understand the findings and conclusions of the overall report.

- Section B presents information and agri-environmental indicators that are specifically related to environmental farm management and agricultural production intensity.
- Sections C through F present agri-environmental indicators related to soil quality, water quality, air quality and agro-ecosystem biodiversity.
- Section G presents eco-efficiency indicators for the food and beverage industry.
- Section H summarizes indicator findings on a regional basis.

We wanted this report to be understood by lay persons, not just scientists and agricultural experts, and so we have tried to minimize the use of technical words and concepts. Any specialized terms used are italicized the first time they appear in the text and defined in a glossary at the end of the report. Each chapter is written to stand alone and may be cited as an individual document (the correct citation is given on page ii). However, we encourage readers to peruse the entire report.

As mentioned earlier, the work on agri-environmental indicators involves a process of continuous improvement. Hence, although some indicators have been reported on previously, improvements have been made to methodologies and datasets in most cases. Results and trends for these indicators have therefore not only been updated with more recent data, but all calculations have been re-done for the entire period covered (see Chapter 2 for details). It is therefore not appropriate to compare the results provided in this report with those in the previous report, published in 2000. It is better to consider this report as "replacing" the previous AEI report.

Finally, since space is limited in a printed report, the information presented here must be viewed as an overall summary of the work done on Canadian agri-environmental indicators. Interested readers are invited to consult the on-line version of this report, where they may find additional details and more detailed technical descriptions of each indicator, particularly the detailed methods of calculation and meta-data information. Over time they may also find updated information and results published on-line, as scientific research and efforts to address AEI gaps and limitations continue, furthering AAFC's commitment to continuously improve agri-environmental indicators.

REFERENCES

Agriculture and Agri-Food Canada, 2003. *Sustainable Agriculture: Our Path Forward*, AAFC's third Sustainable Development Strategy (SDS). Ottawa (Ont.). www.agr.gc.ca/policy/environment/pdfs/sds/SDSIII_e.pdf

Bond, W.D., D. O'Farrell, G. Ironside, B. Buckland, and R. Smith, 2005. *"Current Status, Trends, and Perceptions Regarding Environmental Indicators and State of the Environment Reporting in Canada"*. Background paper to an *Environmental Indicators and State of the Environment Reporting Strategy, 2004–2009*. Environment Canada, National Indicators and Reporting Office, Gatineau (Que.). www.ec.gc.ca/soer-ree/English/documents/bg_paper1_e.cfm

McRae, T., 2000. *"Introduction"*. In McRae T., C.A.S. Smith, and L.J. Gregorich (eds) 2000. Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. Agriculture and Agri-Food Canada, Ottawa. www.agr.gc.ca/env/naharp-pnarsa/ *(Go to related documents)*

McRae, T., C.A.S. Smith, and L.J. Gregorich (eds), 2000. *Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project*. Agriculture and Agri-Food Canada, Ottawa. www.agr.gc.ca/env/naharp-pnarsa/ *(Go to related documents)*

Organisation for Economic Co-operation and Development (OECD), 2001. *Environmental Indicators for Agriculture, Volume 3: Methods and Results*. OECD. Paris (France). www.oecd.org/dataoecd/0/9/1916629.pdf *(Executive Summary only)*

2. Assessing the Environmental Sustainability of Agriculture

■ SUMMARY

This chapter presents an overview of the approach used by AAFC to conduct comprehensive national assessments and report on the key environmental issues that the Canadian agri-food sector faces. By agri-food sector, we mean both primary agriculture and the food and beverage processing industry. Section A presents the approach used to assess five key aspects of the environmental sustainability of agro-ecosystems, in the context of primary agriculture: environmental farm management, *soil quality, water quality, air quality and agricultural biodiversity. Section B discusses the approach that is currently being developed to assess eco-efficiency of the food and beverage industry, likewise with a focus on five aspects: energy, greenhouse gas emissions, water use and liquid* effluents, *solid organic waste generation and packaging wastes. This attempt to provide a more comprehensive assessment of the agri-food sector by including food and beverage processing represents a much broader approach than in previous assessments of environmental sustainability in agriculture.*

A) Primary agriculture

AUTHORS:
W. Eilers and
A. Lefebvre

ADAPTED FROM:
Smith and McRae, 2000

■ CONTEXT

Agro-ecosystems result from human manipulation of natural ecosystems to produce food, fibre and other products for society. This transformation begins when the land is first cleared of natural vegetation, and domestic crops are seeded and harvested. Production-enhancing techniques may be employed, such as tilling of the soil, supplementing natural precipitation with *irrigation*, applying additional nutrients and controlling weeds and animal pests. Agro-ecosystems, like natural ecosystems, are dynamic, with a constant flow of energy, water and chemical elements entering and leaving the system in cycles. The rates of flow of these components may, however, differ considerably between the two systems.

Interactions between the practice of agriculture and the surrounding environment are inevitable. However, this does not mean that environmental degradation is also an inevitable consequence of agriculture. To an ever-greater extent, we are learning ways to practice agriculture that can minimize environmental degradation and even enhance natural ecosystems, for example, by providing wildlife habitat or storing carbon in soils.

Understanding how well agriculture and agri-food systems manage and conserve natural resources and how compatible they are with the natural systems and processes in the broader environment is critical for assessing their environmental sustainability. Agri-environmental indicators (AEIs) can be defined as "measures of key environmental conditions, risks, or changes resulting from agriculture, or of management practices used by producers" (McRae et al. 2000). They are the main tools harnessed in this report to outline the current scientific understanding of these interactions between agriculture and nature. Survey based information is also drawn on to provide additional context for the evaluation of environmental sustainability.

AGRI-ENVIRONMENTAL INDICATORS

Agri-environmental indicators are a practical means of assessing environmental sustainability by combining scientific knowledge and understanding with available information on resources and agricultural practices. To ensure credibility and rigour in this assessment process, all agri-environmental indicators have to meet a set of fundamental criteria. They have to be:

- ***policy relevant:*** indicators should relate to the key environmental issues that governments and other stakeholders in the agriculture sector are seeking to address;
- ***scientifically sound:*** indicators should rely on methodologies that are scientifically sound, reproducible, defensible and accepted, recognizing that their development may involve successive stages of improvement;
- ***understandable:*** the significance of the indicator values that are reported should be readily understood by policy makers and the wider public;
- ***capable of identifying geospatial and temporal change:*** indicators should allow spatial and temporal trends to be identified;
- ***feasible:*** indicators should make use of existing data as much as possible and they should not be prohibitively expensive to develop.

To further guide our efforts to identify and develop appropriate indicators of environmental sustainability in agriculture, we used a conceptual framework that characterizes the environmental aspects and influences of agricultural production practices. This framework, called the "Pressure–Outcome–Response Framework," considers three broad areas that, when applied to agri-environmental sustainability, can be described as follows:

- ***Pressure:*** environmental stresses that may influence important aspects of agricultural production, such as the selection of crops and management practices used for production.
- ***Outcome:*** ultimate impact of agricultural production on the health of the environment (soil, air, water, biodiversity).
- ***Response:*** use by producers of key management options which influence the impact of agriculture on the environment.

While this framework provides a context for individual indicators, agricultural production and its interactions and linkages with the environment are complex and multi-faceted. Additional (non-environmental) pressures or responses such as markets, government policies and private expenditure also influence the sector's environmental performance. Although these additional pressures are not covered in this assessment, Chapter 3 discusses the efforts that are under way to link them to the agri-environmental indicators.

CALCULATION METHOD

The agri-environmental indicators that are covered in this report are designed to be responsive to changes in key land use and farm management practices, to lend themselves to broad spatial scales and to zero in on the agriculture sector's positive and negative impacts on the environment. They typically fall into one of three categories:

- ***risk indicators:*** estimate of the likelihood of a potential environmental impact;
- ***state indicators:*** estimate of the actual presence and degree of an impact;
- ***eco-efficiency indicators:*** estimate of resource use efficiency, typically by comparing inputs and outputs of some material.

Agri-environmental indicators are calculated using mathematical models or formulas that integrate biophysical information (on soil, climate and landscape), which is taken mainly from the *Soil Landscapes of Canada*, with land use and farm management data from the *Census of Agriculture* and other custom data sets (from provincial agencies, private sector, remote sensing, etc.) generalized to portray an environmental condition on the landscape at a given time. These mathematical models and formulas have been adapted or developed on the basis of scientific knowledge and understanding of the interactions between various aspects of agricultural practices and the environment. This approach was selected instead of, for example, detailed environmental monitoring, because it lends itself well to calculations at broad spatial scales, can isolate the specific impact of agriculture on the environment, eliminates the time lag between land use or management change and actual measurable impact, and is compatible with forward looking integrated economic/environmental models used for policy analysis (see Chapter 5).

Summarized results from the Census of Agriculture, special surveys such as the Farm Environmental Management Survey (Statistics Canada, Agriculture Division 2002) or combinations of these two sources are also used in this report to complement the information provided by the agri-environmental indicators. These results are not considered indicators per se, but are nevertheless important for carrying out a comprehensive assessment of environmental sustainability of agriculture.

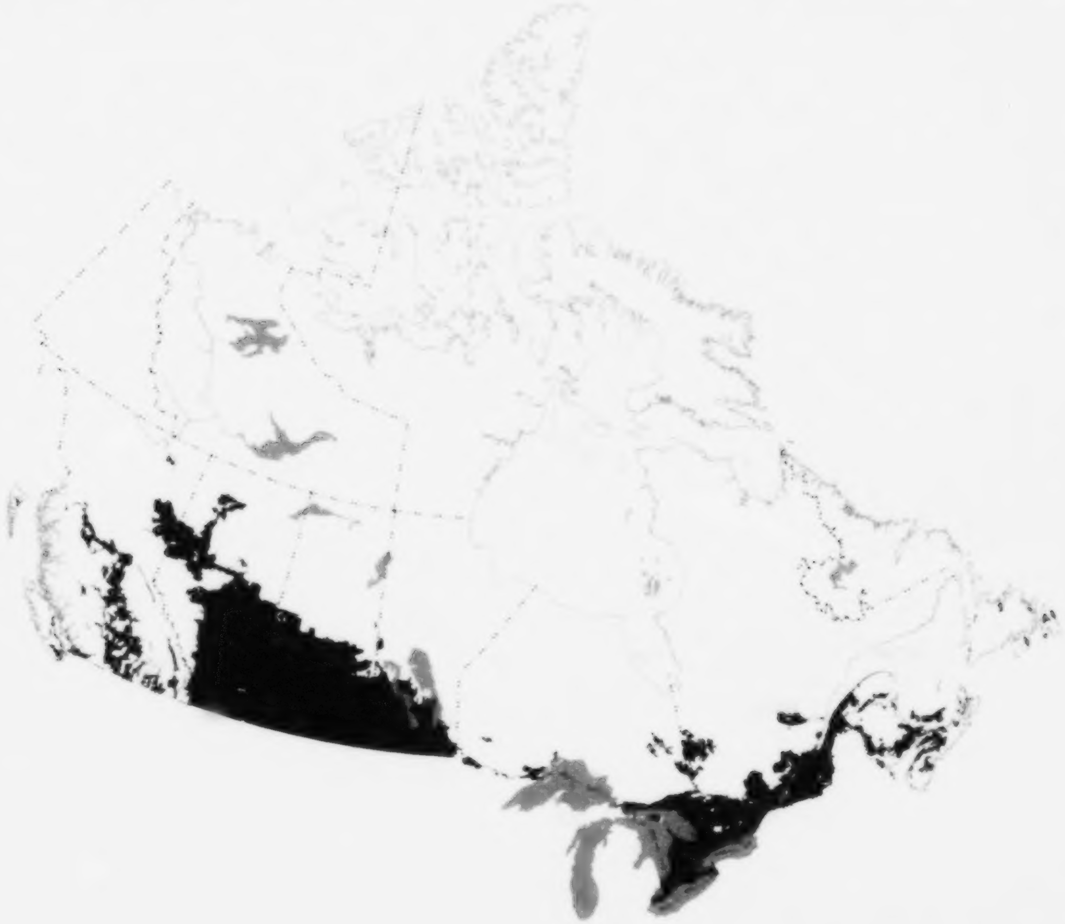
Geospatial framework: Indicators are designed to estimate changes and trends in time and space. Most indicators use a suite of data that are collected at various temporal and geographical scales. A great deal of effort goes into developing proper ways of interpreting and integrating these data in a common geospatial framework to allow indicator calculation.

The spatial basis, or the areas used for most of the indicator model calculations reported on in this document, are polygons of the Soil Landscapes of Canada (SLC) map series. These maps portray generalized soil and landscape information at a scale of 1:1 million and are integrated into the *National Ecological Framework for Canada*. In 2004, SLC polygons (landscape units) for agricultural regions of Canada were updated to provide more accurate placement of *polygon* boundaries and, more importantly, to include additional information on the soils found within the polygon mapping units. Polygon size varies, ranging from about 10,000 ha to 1 million ha. Using these mapping units allows soil and landscape data to be integrated with farm management data for indicator calculation. Results can then be rolled up and reported at larger scales suitable for a national assessment like this one.

A common set of agricultural SLC polygons was used to calculate the agri-environmental indicators described in this report. For most of Canada, in order to be included in the set, the polygons had to have at least 5% of their area reported as farmland in each of the 1981, 1986, 1991, 1996 and 2001 Census years. As a result of these requirements, many polygons in the fringe areas where agricultural activities are highly dispersed were excluded from the calculations. Agriculture in the Yukon Territory, the Northwest Territories and Nunavut was excluded from the study, as was agriculture along the northern fringes or in outlying areas of the provinces. In the Atlantic Provinces, where agriculture may represent only small portions of SLC polygons, all areas reporting agriculture in the Census years were included in the analysis. Figure 2-1 shows a map of the 2,780 polygons that met this requirement, defining the extent of the agricultural area covered by agri-environmental indicators in this report.

Re-allocation of data from the Census of Agriculture (AAFC 2004): Most indicators use information on crops, land use, land management and livestock derived from the Census of Agriculture. However the Census of Agriculture is compiled using Statistics Canada's geographic units, which are aligned to political boundaries and cannot easily be linked to biophysical information such as that embodied in the Soil Landscapes of Canada. An area-weighting method was devised to calculate and re-assign the Census data to the SLC polygons. Data suppression was maintained by Statistics Canada to protect producer confidentiality after the re-allocations. AAFC then estimated values for suppressed locations for use in the calculations. Since the boundaries of the Census areas change from year to year based on the number of respondents in an area, this reassignment of data to SLC polygons was done for each Census

Figure 2-1: Extent of agricultural area covered by Agri-Environmental Indicators



year. The Census of Agriculture data for the years 1981, 1986, 1991, 1996 and 2001 were used in most of the indicators, and calculations are therefore typically done for each of these Census years.

■ LIMITATIONS

Our goal in developing agri-environmental indicators for national- to regional-scale reporting is not to measure each issue in the field, but rather to draw on our scientific knowledge and understanding of the processes involved in evaluating the available information. This results in the indicators being subject to a number of general limitations that are described below. Particular limitations that apply to individual indicators are described in the chapter concerned.

Knowledge gaps: Indicator development is dependent on our understanding of the ecosystem processes involved. The scientific community cannot produce credible assessments of environmental health without having a good grasp of the functions, transformations and interrelationships that are involved. Calculation methodologies are at varying stages of development, since the work in some areas has been under way for some time, while in other areas quantification efforts are at a very early stage of development. In some cases, there may also be a lack of knowledge about causalities and linkages between indicators.

In this assessment, indicators are typically calculated using mathematical models or numerical algorithms that were developed and tested at the field level. This approach provides a good theoretical foundation to help define how management practices interact with landscape conditions and ecological processes to produce an environmental effect. However, any modelling approach is an estimation, which is limited by our incomplete and still evolving scientific knowledge of these interactions. Confidence is lessened when the field-tested models are used at broader scales. This is why national evaluations such as this one are limited to potential risk assessments for some issues as opposed to an effort to determine actual physical contributions to the environment from agriculture.

Data issues: The data needed to calculate the indicators were not always available or not available for the entire country. This occurs either because a particular parameter has not been measured or surveyed, or because data have been suppressed for reasons of confidentiality (e.g. Statistics Canada may suppress livestock numbers and associated land areas when there are only a few instances of a particular farm activity in a given area). When tallied over an entire province or ecozone, considerable data may be lost and results skewed. Alternative approaches are being developed and, when possible, used to overcome these limitations and obtain or estimate the missing information.

Agri-environmental indicators are key science-based tools that can be used to provide a picture of environmental sustainability in agriculture.

Indicators are also often calculated using data items that have been re-allocated to a different spatial basis from that at which they were collected. A prime example of this approach is the re-assignment of Statistics Canada Census of Agriculture data to the Soil Landscapes of Canada polygons. Experts have developed rational means of doing such spatial re-allocation; however, issues still remain that can result in errors in the information. In many regions of the country, agriculture is the dominant land use and minor errors in this assignment should not unduly influence the indicator results. However, much of Canada's agricultural production takes place on landscapes where agriculture is not the dominant land use, and indeed where agriculture may occur on such small proportions of the SLC polygon area that there is no way of being certain that the re-allocation of data is correct. Efforts are continuing to improve this re-allocation process through the use of satellite data, manual data checks and validations against field observations.

Recent improvements to the SLC data have allowed the soils and landscapes in the SLC polygons to be represented to a greater extent in the indicators; however, the data on specific soil properties that are required to calculate many of the indicators are often based on relatively crude estimates, increasing the uncertainty surrounding indicator analysis.

Reliability: In developing agri-environmental indicators, scientists are forced to operate within their partial knowledge of the system and within the precision limits of the data at their disposal. All measured data used in calculating the indicators have an intrinsic uncertainty associated with them. In this report we were unable to use statistical methods to determine the actual uncertainty associated with the indicator results. This is an issue that we plan to address in future indicator analyses and reports.

■ UNDERSTANDING RESULTS

Agri-environmental indicators are key science-based tools that can be used to provide a picture of environmental sustainability in agriculture. Despite their limitations, the indicators are sensitive to changing farm management practices and are able to show patterns of environmental risk and conditions that reflect the intensity of agricultural production in regions across Canada. They provide a trend line over time that indicates whether the agriculture sector is moving towards or away from environmental sustainability. In this regard, they can be used to point out areas in which further research and investigation are required before actions can be taken, and provide useful additional information to decision makers for developing and evaluating agricultural policy. The indicator results presented in this report are designed to provide information on the environmental risks and conditions in agriculture at a regional to national scale. This information can be used to provide a report card for producers, consumers and the international community on broad trends in the environmental performance of Canadian agriculture.

Map presentations for indicator results represent the most recent assessments of the conditions, which correspond to the status of the indicators as of 2001. In these map presentations, entire SLCs or other spatial polygons are assigned a value. However, the reader must be aware that the results apply only to the agricultural portion of these polygons and that, within a given area, there will undoubtedly be zones of greater and lesser concern that the indicator averages out to a single value. The aggregated result may obscure local reality, and because of this, as well as the various limitations described above, the indicators cannot be interpreted as showing any specific on-site conditions such as at an individual farm.

The trends in an indicator over time are just as important as the current condition or status of the indicators. This aspect is generally presented in tabular format, setting out actual results for Canada and individual provinces that cover each year for which the indicator was calculated. The agriculture sector's interactions with the environment are complex, and caution must be exercised in seeking to make overall interpretations from the trends observed in individual indicators. Positive trends in one indicator may lead to negative trends in another. A national and regional summary of indicator trends is presented in Section II.

The ideal approach for assessing the environmental sustainability of the conditions and risks identified by the indicators is to compare the results with science-based reference thresholds (such as environmental quality standards). We have attempted to develop a standard classification framework for all indicators (Table 2-1), which consists of a five-class rating

Table 2-1: Description of indicator classes for risk indicators

Classes	Meaning	Implication
1 – Very low risk	In general this level of risk is **negligible**. Agri-environmental health is likely to be maintained or enhanced over time.	A more detailed analysis of the situation is warranted, to understand the various factors that have contributed to this rating. Some potential may exist to export policy and program approaches to areas of higher risk.
2 – Low risk	In many cases this level of risk may be **acceptable**. Agri-environmental health is at low risk of being significantly degraded.	Continued adoption of beneficial management practices to better match the limitations of the biophysical resource may improve sustainability in some areas. Specific (policy or program) actions not necessarily warranted.
3 – Moderate risk	**Awareness** of the situation is important. Agri-environmental health is at moderate risk of being significantly degraded.	The trend towards or away from sustainability needs to be assessed. More attention should be directed locally to promoting the adoption of beneficial management practices in order to better match the limitations of the biophysical resource and reduce this risk.
4 – High risk	Heightened **concern** is warranted. Under current conditions, agri-environmental health is at high risk of being significantly degraded.	A more thorough local assessment is probably warranted. Additional efforts and targeted actions are likely needed locally to better match management practices to the limitations of the biophysical resources.
5 – Very high risk	**Immediate attention is likely required. Under current conditions, agri-environmental health is at very high risk of being significantly degraded.**	**A more thorough local assessment is warranted. Concrete and targeted actions are likely needed locally to better match management practices to the limitations of the biophysical resources. It may be necessary to consider alternate land uses to reduce the risk.**

Note: A similar scheme may be applied to non-risk indicators with slight variations in the class description, meaning and implications.

be used to provide a report card for producers, consumers and the international community on broad trends in the environmental performance of Canadian agriculture.

Map presentations for indicator results represent the most recent assessments of the conditions, which correspond to the status of the indicators as of 2001. In these map presentations, entire SLCs or other spatial polygons are assigned a value. However, the reader must be aware that the results apply only to the agricultural portion of these polygons and that, within a given area, there will undoubtedly be zones of greater and lesser concern that the indicator averages out to a single value. The aggregated result may obscure local reality, and because of this, as well as the various limitations described above, the indicators cannot be interpreted as showing any specific on-site conditions such as at an individual farm.

The trends in an indicator over time are just as important as the current condition or status of the indicators. This aspect is generally presented in tabular format, setting out actual results for Canada and individual provinces that cover each year for which the indicator was calculated. The agriculture sector's interactions with the environment are complex, and caution must be exercised in seeking to make overall interpretations from the trends observed in individual indicators. Positive trends in one indicator may lead to negative trends in another. A national and regional summary of indicator trends is presented in Section H.

The ideal approach for assessing the environmental sustainability of the conditions and risks identified by the indicators is to compare the results with science-based reference thresholds (such as environmental quality standards). We have attempted to develop a standard classification framework for all indicators (Table 2-1), which consists of a five-class rating

Table 2-1: Description of indicator classes for risk indicators

Classes	Meaning	Implication
1 – Very low risk	**In general this level of risk is negligible. Agri-environmental health is likely to be maintained or enhanced over time.**	**A more detailed analysis of the situation is warranted, to understand the various factors that have contributed to this rating. Some potential may exist to export policy and program approaches to areas of higher risk.**
2 – Low risk	In many cases this level of risk may be **acceptable**. Agri-environmental health is at low risk of being significantly degraded.	Continued adoption of beneficial management practices to better match the limitations of the biophysical resource may improve sustainability in some areas. Specific (policy or program) actions not necessarily warranted.
3 – Moderate risk	**Awareness** of the situation is important. Agri-environmental health is at moderate risk of being significantly degraded.	The trend towards or away from sustainability needs to be assessed. More attention should be directed locally to promoting the adoption of beneficial management practices in order to better match the limitations of the biophysical resource and reduce this risk.
4 – High risk	**Heightened concern is warranted. Under current conditions, agri-environmental health is at high risk of being significantly degraded.**	**A more thorough local assessment is probably warranted. Additional efforts and targeted actions are likely needed locally to better match management practices to the limitations of the biophysical resources.**
[illegible]	[illegible]	[illegible]

Note: A similar scheme may be applied to non-risk indicators with slight variations in the class description, meaning and implications.

system, in which each class has a general meaning in terms of environmental sustainability or a given implication from a policy perspective. However, thresholds that would allow us to differentiate between the five classes are typically not available, and most of the indicators were established on the basis of expert knowledge, an approach that is subject to additional interpretation. AAFC is currently working in partnership with Environment Canada to develop a systematic approach to establishing reference thresholds.

The indicators presented in this report are a vehicle for communicating information in summary form about important issues from a biophysical perspective. However their use is not strictly limited to showing present status and trends. While in most cases the direction of change may be unambiguous in terms of the environmental impact of an increase or a decrease in a specific indicator, it is preferable not to interpret indicators in isolation. There are often important trade-off questions, and one indicator cannot easily be interpreted without considering a broader framework, such as determining the overall socio-economic and environmental costs and benefits associated with the adoption of alternative land use or management practices. As part of its efforts to develop agri-environmental indicators, AAFC is also developing tools and approaches for linking these indicators to economic and policy models, in order to provide guidance for policy and program evaluation and development. Use of the indicators in policy development is discussed in greater detail in Chapter 5.

■ REFERENCES

Agriculture and Agri-Food Canada (AAFC), 2004. *Census of Agriculture: Soil Landscapes of Canada* (SLC), v.3 and *Water Survey of Canada sub-sub drainage area* (WSCSSDA), v.5, Re-allocation. Unpublished data for research purposes. AAFC, Ottawa (Ont.).

Ecological Stratification Working Group, 1995. *A National Ecological Framework for Canada.* Report and national map at 1:7,500,000 scale. Agriculture and Agri-Food Canada and Environment Canada, Ottawa (Ont.). http://sis.agr.gc.ca/cansis/publications/ecostrat/intro.html

McRae, T., C.A.S. Smith, and L.J. Gregorich (eds), 2000. *Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project.* Agriculture and Agri-Food Canada, Ottawa (Ont.). www.agr.gc.ca/env/naharp-pnarsa/ *(Go to related documents)*

Smith, C.A.S. and T. McRae, 2000. *"Understanding and Assessing the Environmental Sustainability of Agriculture".* In McRae T., C.A.S. Smith, and L.J. Gregorich (eds), Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. Agriculture and Agri-Food Canada, Ottawa (Ont.). www.agr.gc.ca/env/naharp-pnarsa/ *(Go to related documents)*

Statistics Canada, 2002. *Farm Environmental Management in Canada.* Statistics Canada, Agriculture Division, Ottawa (Ont). www.statcan.ca:8096/bsolc/english/bsolc?catno=21-021-M

B) Food and Beverage Processing Industry

AUTHORS:
M. Marcotte,
D. Maxime
and Y. Arcand

■ CONTEXT

The food and beverage processing industry (FBI), which is classified as a manufacturing industry, is a major intermediary in the food chain. It is the pathway of almost half of Canada's raw primary agricultural output, and around 70% of FBI's inputs come, directly or indirectly, from agricultural production or fisheries. These inputs are processed into a wide range of food products prior to shipping to domestic (75%) or international consumers (25%). It is an important industry in all provinces and generally ranks among the top three manufacturing sectors in terms of shipments and jobs. The food and beverage industry uses a wide range of technologies to achieve its two primary objectives: to carry out the desired processing (e.g. bread production); and to stabilize foods and beverages so they will have a longer shelf life (e.g. milk *pasteurization*). The manufacturing steps and processes for most foods and beverages are well known and usually fall into the following categories:

> *Five issues have been identified for the development of eco-efficiency indicators for the food and beverage processing industry.*

- preparing raw materials (washing, cutting, mixing, *homogenization*);
- utilizing heat (*sterilization*, pasteurization);
- utilizing cold (refrigeration, freezing);
- removing water (drying, evaporation, pressing, filtration);
- modulating product composition (pH, salts, sugars, preservatives, smoking, *fermentation*);
- modulating the product environment (*dissolved oxygen*, modified or controlled atmosphere, active packaging); and
- separating/concentrating the components of agricultural products (extraction, membrane, distillation).

As in all other sectors, food and beverage processing plants are required to meet various environmental performance standards, which may be critical for competing on the world market. In manufacturing food products, the food and beverage industry uses a significant amount of resources (raw agricultural products or ingredients, energy, water). It also generates gaseous emissions, liquid wastes and solid organic residues. While most packaging waste is generated at the consumption level, almost all of it enters the system at the processing stage. Five issues (or environmental loads) have been identified for the development of eco-efficiency indicators for the food and beverage processing industry:

- Energy use;
- Greenhouse gas (GHG) generation;
- Water use and waste water production (e.g. black water, effluents and contaminants);
- Solid organic residue generation; and
- Packaging waste generation.

■ THE INDICATORS

The indicators will be based on the concept of eco-efficiency, which is a widely recognized concept in the manufacturing industry that is often used to help companies characterize and meet both environmental and economic objectives (Verfaillie and Bidwell, WBCSD 2000). Eco-efficiency is defined as a process during which goods or services of greater value or in greater quantity are produced using fewer raw materials, and less water and energy, thereby reducing natural resource depletion and pollution (NRTEE 2001). The indicators essentially compare the environmental factors or "loads" to the quantity of products manufactured. While this actually provides an intensity rating

Table 2-2: Coverage plan for the food and beverage industry eco-efficiency indicators

Sub-sectors (NAICS code)	
1	Grain and Oilseed Milling excluding Breakfast Cereal Manufacturing (3112 – 31123)
2	Sugar and Confectionery Product Manufacturing (3113)
3	Fruit and Vegetable Preserving and Specialty Food Manufacturing (3114)
4	Dairy Product Manufacturing (3115)
5	Meat Product Manufacturing (3116)
6	Seafood Product Manufacturing (3117)
7	Bakeries and Tortilla Manufacturing including Breakfast Cereal Manufacturing (3118 + 31123)
8	Beverage Manufacturing (3121)
Location	
1	Atlantic Provinces
2	Quebec
3	Ontario
4	Prairies
5	British Columbia
6	Canada
Plant size	
1	10 to 49 employees
2	50 to 199 employees
3	200 employees or more

Note: Because of the very low number of plants in the Northwest Territories, Yukon and Nunavut, they cannot be reported in our research for reasons of confidentiality and privacy of information.

(which is the inverse of efficiency), the use of a common denominator (physical production unit) will facilitate comparison within each subsector for each of the five issues of interest.

The indicators themselves are reported according to a coverage plan, based on sub-sector, geographic location and processing plant size (see Table 2-2). This will allow an assessment of environmental performance trends by establishment size and by region within the same sector. Because of the inherent differences of the industry sectors, cross-sector comparison of indicators will not be possible, except for one component of the greenhouse gas indicator, which is not based on physical production units. Results for the indicators are relative, in that individual performances are ranked in comparison to the sector's eco-efficiency leaders.

■ CALCULATION METHOD

An inventory approach (mass and energy balances between inputs and outputs) at the process and plant levels will be used to quantify the indicators in each of the five categories mentioned above, in an integrated fashion (see Figure 2-2). This is necessary to prevent double-counting and to take pollution movement into account. For example, wash water (liquid effluent) can be treated on site to remove solids and the pollution load, but the resulting *sludge* becomes a solid organic residue that is frequently sent to a landfill site. The methodology will be based on environmental management and *life cycle assessment* standards (e.g. ISO 14000, ISO 14040). Data from specialized surveys or on-site experiments in production plants will be used to calculate the various required parameters.

The indicator concepts will first be tested, evaluated and validated using data from past surveys [e.g. the Annual Survey of Manufactures (Statistics Canada 2005a) and the Annual Industrial Consumption of Energy Survey (Statistics Canada 2005b) and the Industrial Water Use Survey (Environment Canada 2003)]. Individual plants will then be surveyed based on the above coverage plan to gather data that is not readily available (e.g. solid organic residues, water effluent quality) and to update survey information (e.g. water use). On-site diagnostics are also planned to measure parameters or generate data that cannot be obtained through surveys (e.g. in-process greenhouse gas generation, amount of water used for specific operations, etc.). This data will be used to generate coefficients that can then be used in conjunction with survey results to estimate missing values required for indicator calculation.

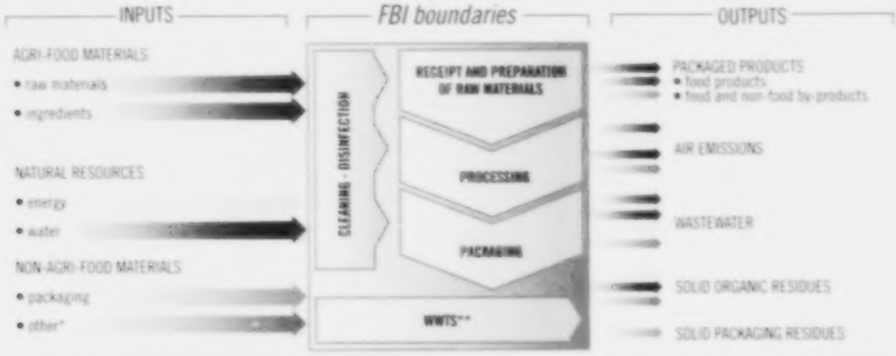
■ LIMITATIONS

The main limitation applying to these indicators will be the availability and quality of data required for the calculations. Plans are in place to bridge the most pressing data gaps, complementing existing survey data with a series of on-site diagnostics at the plant level (10 to 20 per year) over a four-year period, but some gaps will remain.

■ RESPONSE OPTIONS

In practice, the food and beverage industry's environmental performance is influenced by individual plants' business practices including internal policies, management system and staff awareness and by the manufacturing processes themselves. Some of the available business practice options can be grouped under the label "best operating practices" (BOPs), such as those recently described in a European Commission publication (JRC, IPTS 2003). Three criteria are

Figure 2-2: Inventory approach used to qualify the Food and Beverage Industry indicators


INPUTS
FBI boundaries
OUTPUTS
AGRI-FOOD MATERIALS
• raw materials
• ingredients
NATURAL RESOURCES
• energy
• water
NON-AGRI-FOOD MATERIALS
• packaging
• other*
CLEANING - DISINFECTION
RECEIPT AND PREPARATION OF RAW MATERIALS
PROCESSING
PACKAGING
WWTS**
PACKAGED PRODUCTS
• food products
• feed and non-food by-products
AIR EMISSIONS
WASTEWATER
SOLID ORGANIC RESIDUES
SOLID PACKAGING RESIDUES

* Materials not incorporated in food (e.g. cleaning agents)
** Wastewater treatment system (if applicable)

generally used to prioritize and classify these practices: the investment cost to adopt them, quantification of the anticipated environmental gains (made apparent by the indicators), and the return-on-investment period. Once calculated, the indicators will shed light on the extent to which these best operating practices are being implemented and, in a sense, quantify a company's efforts towards environmental sustainability (Richard 2003; Industry Canada 2001). As indicator development proceeds, the specific quantitative contribution of various BOPs will be determined.

■ REFERENCES

Environment Canada, 2003. *Industrial Water Use, 1996*. Environment Canada, Sustainable Water Use Branch, Ottawa (Ont.). www.ec.gc.ca/water/en/info/pubs/sss/e_ind96.htm

Hendrik, A. Verfaillie and Robin Bidwell (eds), 2000. *Measuring Eco-efficiency: A Guide to Reporting Company Performance*. World Business Council for Sustainable Development (WBCSD), Geneva (Switzerland). www.wbcsd.org/DocRoot/RvsdQEHXvwt12dx39nCF/MeasuringEE.pdf

Industry Canada, 2001. *Three Steps to Eco-efficiency*. Industry Canada, Ottawa (Ont.). http://strategis.ic.gc.ca/epic/internet/inee-ee.nsf/vwapj/finaltool.PDF/ $FILE/finaltool.PDF

Joint Research Centre of the European Commission (JRC), Institute for Prospective Technological Studies (IPTS), 2003. *Integrated Pollution Prevention Control (IPPC): Draft Reference Document on Best Available Techniques in the Food, Drink and Milk Industry*. Seville (Spain). www.epa.ie/Licensing/IPPCLicensing/BREFDocuments/FileUpload,501,en.pdf

National Round Table on the Environment and the Economy (NRTEE), 2001. *Eco-efficiency Indicators. Calculating Eco-Efficiency Indicators: A Workbook for Industry*. NRTEE, Ottawa (Ont.). www.nrtee-trnee.ca/Publications/HTML/ Complete-Documents/Eco-efficiency_Workbook/index.html

Richard, F. (ed.), 2003. *Waste Management Guide for Small and Medium Enterprises – Canadian Version*. Éditions Ruffec and NI Environnement, Montreal (Que.). www.qc.ec.gc.ca/dpe/Anglais/dpe_main_en.asp?innov_guide_mat_residuelles

Statistics Canada, 2005a. *Annual Survey of Manufactures*. Statistics Canada, Ottawa (Ont.). www.statcan.ca/english/sdds/2103.htm

Statistics Canada, 2005b. *Annual Industrial Consumption of Energy Survey*. Statistics Canada, Ottawa (Ont.). www.statcan.ca/english/sdds/5047.htm

3. Driving Forces Affecting the Environmental Sustainability of Agriculture

AUTHORS:
B. Junkins,
H. Clark,
R.J. MacGregor
and T. McRae

ADAPTED FROM:
MacGregor and McRae, 2000

■ SUMMARY

The driving forces affecting agriculture have evolved considerably over the past 20 years. Globalization, market pressures and technological innovations have spurred Canadian agriculture to increase output and productivity in an effort to keep pace with growing domestic and world demand. To achieve this, the sector has undergone structural changes, some of which have environmental implications. Over the past two decades, the social preferences of Canadians have also evolved. Concerns have been raised about the environmental costs of food production. Canadians have supported a growing array of domestic and international agreements and regulations designed to protect the environmental systems with which agriculture interacts. The sector has responded to these driving forces in many ways. More and more, agriculture is looking for ways to integrate environmental factors into decision-making processes on the farm and in policy development. The sector is continually adopting new technologies and developing and carrying out voluntary initiatives to improve environmental outcomes. This chapter reviews some of the changes in these driving forces which have likely influenced the agriculture sector's environmental performance in ways that may be measured by the agri-environmental indicators presented in this report.

■ INTRODUCTION

Agriculture is inextricably connected to the broader policy, economic and social trends of the world. Globalization, trade agreements, changing domestic and world demand, changing market structure and technological innovations all have an influence on the decisions made by agricultural producers. Farmers consider the overall operating context shaped by these forces and select production strategies that will allow them to achieve desired outcomes most efficiently. These forces also affect the environmental risks and benefits of agricultural production, which can vary significantly depending on the methods of production selected and the local ecosystems to which they are applied. The Pressure–Outcome–Response Framework that is used to guide the development of the agri-environmental indicators (see Chapter 2) integrates these socio-economic pressures (driving forces), which affect the management decisions (response) of farmers, and ultimately, the health of the environment (outcome). All of the pressures, outcomes and responses are interrelated.

Throughout the past century these driving forces have evolved, becoming more complex, changing even more quickly in recent years. New issues have emerged as the farm sector continues to broaden its environmental approach from a limited "on-farm" resource conservation approach to one that addresses the effects of agricultural operations on the larger ecosystem. Driving forces will continue to evolve, and risks to the environment will remain a concern as output expands. Policy, technology and other instruments will be required to respond to these driving forces so that economic, environmental and social objectives can all be achieved.

■ MARKET DEMAND

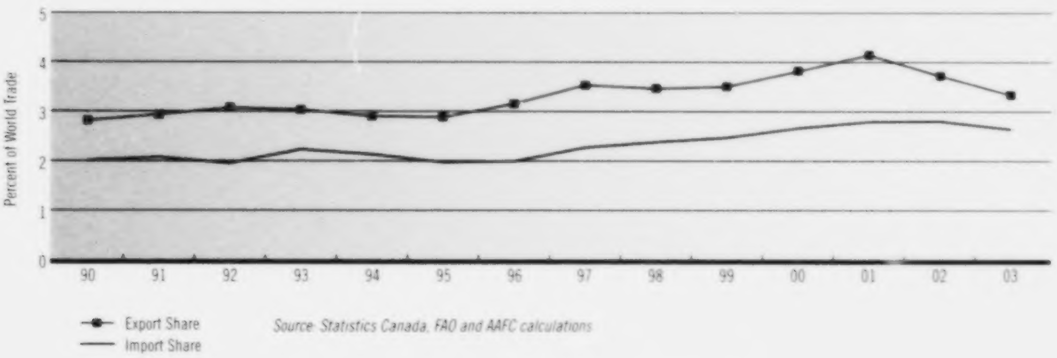
The expanding world population, higher disposable incomes and increased life expectancies in North America and elsewhere have boosted global demand for food. With rising incomes in both developed and developing countries, consumer preferences are changing and diets are becoming more varied and include more expensive livestock products and fresh fruits and vegetables along with the more traditional cereals. Industrial demand for non-food agricultural products (e.g. *biofuels*, *bioplastics*, building materials, *nutraceuticals*) is also growing.

The rising global demand for food and other agricultural products has been accompanied by globalization of markets and trade liberalization. Canada, with its large land base, limited population, ample water supplies and competitive industry, has been able to respond to this market-driven opportunity (Figure 3-1). The industry itself has set targets for increased agriculture and agri-food trade. For example, in 1997 the Canadian Agricultural Marketing Council established a target for Canada to achieve a 4% share of world agriculture and agri-food trade by 2005. This objective was actually achieved in 2001. Agriculture and agri-food production and trade can also be negatively affected by climate conditions and market forces. For example, drought, border closure due to technical issues (such as the discovery of a case of *Bovine Spongiform Encephalopathy*) and the appreciating Canadian dollar (30% gain relative to the US dollar) are all factors that affected trade between 2002 and 2004.

The need to increase competitiveness and productivity in the global economy has spawned research initiatives, changes in government policies (such as income support programs) and marketing efforts. It has also led to structural changes in the industry, including the following:

- the development and use of new production methods aimed at enhancing competitiveness (improved management systems such as conservation tillage, precision farming);
- changes in the mix of commodities produced, such as the significantly increased production of special crops (between 1991 and 2001, the area of lentils tripled to over 700,000 ha and the area of field peas increased nine-fold to over 1.7 million hectares);
- greater farm size, specialization and production intensity to capture economies of scale (e.g. emergence of a larger and more concentrated hog industry as evidenced by a 26% increase in the number of hogs between 1996 and 2001 and a concurrent 27% decrease in the number of farms reporting hogs);

Figure 3-1: Canada's share of world agriculture and agri-food trade, 1990 to 2003



Source: Statistics Canada, FAO and AAFC calculations

- changes in land use and management practices (e.g. additional use of inputs such as *nitrogen fertilizer* to increase production).

As market signals change, Canada's agricultural sector seeks to adapt to the changing situation. The way it responds to changes in driving forces may have environmental implications for air, soil and water quality, as well as biodiversity, which in turn may call for action.

SOCIAL PREFERENCES

The preferences and expectations of the general population can have an important influence on the agriculture and agri-food sector, and this has been reflected in the sector responses to mounting consumer demands for a safe and reliable food supply. Consumers at home and abroad are increasingly aware of the economic and ecological value of natural resources as well as the environmental risks associated with agricultural production. Canadians also support rural development and employment and the contributions that agriculture makes to national income and trade. Recent public opinion polls in Canada have revealed that, while respondents rated the overall environmental performance of the agricultural sector as positive, they were concerned about certain aspects of agricultural production, such as air, water and soil pollution, the use of chemical pesticides, animal diseases that can be transmitted to humans and genetically modified foods and *biotechnology* (GlobeScan 2003). Consumer choices can also influence farm production practices that affect the environment. For example, the growing market for organic foods (crops produced without chemical fertilizers or synthetic pesticides and not derived from genetic engineering) could lead to reduced risks of chemical and *pesticide* contamination of water in some localized areas. At the same time, organic farming could increase the risk of *pathogen* contamination given the greater use of organic fertilizers and manure.

Changes in public expectations related to the environment and food products have direct ramifications for the agriculture sector. Canadians are generally supportive of initiatives for environmental preservation and protection. Governments have responded to their concerns by adopting a number of strategies that ultimately influence agricultural production and food processing, such as supporting technological research and innovation, implementing policies and voluntary programs to promote environmentally sustainable agriculture and passing regulations to protect the environment.

For the most part, farmers are not compensated for their efforts to reduce environmental risks.

For the most part, farmers are not compensated for their efforts to reduce environmental risks. There is, however, growing public recognition of the environmental benefits that agriculture provides, such as habitat for wildlife, pleasant landscapes, recycling of effluents and solid waste, reduction of greenhouse gas emissions through carbon *sinks* and innovations such as *anaerobic* digesters that capture biogas. Agrotourism and programs sponsored by public interest groups may provide opportunities for farm families to capitalize on these benefits in the future.

GOVERNMENT POLICY

Government policy operates at local, regional, provincial, national and international levels and has a strong influence on the use of agricultural resources. Since the early 20th century, the primary objective of Canadian agricultural policy has been to increase output and promote income stability in a sector that has to grapple with variable weather conditions, volatile commodity prices and strong international competition. Over the past two decades, government support has included funding for agricultural research, long-term capital to finance growth and technology adoption, income stabilization programs, removal of trade restrictions and the maintenance of marketing boards (e.g. the Canadian Wheat Board) and supply management (dairy and poultry). Government support peaked during the 1970s and 1980s when the total amount of direct and indirect subsidies (the Producer Support Estimate, or PSE) reached about 30% of the value of production.

Table 3-1: Examples of environmental initiatives and regulations

International Initiative	**Implications for Agriculture**
United Nations Framework Convention on Climate Change (including the Kyoto Protocol on greenhouse gas emissions)	National response strategy being developed; possible limitations on agricultural emissions of greenhouse gases; potential for offsets trading (including soil sinks).
United Nations Convention on Biological Biodiversity (including the Cartegena Protocol on Biosafety)	Canadian biodiversity strategy developed promoting conservation of crop and livestock biodiversity, habitats and species.
Montreal Protocol on Substances that Deplete the Ozone Layer	Elimination of the use of methyl bromide (an agricultural fumigant) by 2005.
UN Economic Commission for Europe (includes Canada and US) Protocol to Abate Acidification, *Eutrophication* and Ground Level Ozone	Possible limitations on ammonia emissions (agricultural sources are fertilizer and livestock) and nitrogen oxide emissions from farm vehicles.
UNECE Protocol on Persistent Organic Pollutants (POPs)	Some pesticides are POPs; most have been banned from Canadian agriculture.
North American Agreement on Environmental Cooperation	Broad agreement to cooperate to control substances with transboundary effects; chemicals management program could affect pesticide use.
North American Waterfowl Management Plan	Could have an impact on the use of *wetlands* within agricultural boundaries.
Federal Regulations	**Implications for Agriculture**
Canadian Environmental Protection Act (CEPA)	Ammonia and particulate matter (including airborne soil) being assessed under CEPA; limitations on emissions are a possibility.
Canadian Environmental Assessment Act	Requires consideration of environmental impacts of projects prior to implementation; could affect agriculture on federal lands or in cases where federal funds or regulations support or approve projects on private land.
Fisheries Act	Prohibits pollution of waters inhabited by fish; could affect management of irrigation and drainage canals, as well as pesticide use.
Pest Control Products Act	Controls registration and designates use of pesticides based on environmental, human health and other factors.
Species at Risk Act	Possible limitations on the use of agricultural land providing habitat for species at risk.
Provincial and Municipal Regulations	**Implications for Agriculture**
Numerous provincial acts and regulations and municipal bylaws and provisions	Controls imposed on a wide range of agricultural activities (e.g. separation distance to wells, conversion of agricultural land, spreading of manure, manure storage capacity, location of large hog barns); regulations vary by province and by municipality.

Source: MacGregor and McRae (2000)

Realizing that much of this support simply offset what other countries were doing, most developed countries agreed under the auspices of the World Trade Organization and the Agreement on Agriculture (ratified in 1995) to reduce measures that distort trade. Canada has been a strong proponent of measures to reduce trade-distorting agricultural subsidies, as Canadian farmers are considered to be highly competitive in most commodities. From 2001 to 2003, the PSE for Canada stood at a much lower level, i.e. about 20%, than in previous decades as a result of various reforms, such as the elimination of grain transportation subsidies, the decoupling of farm income safety nets from specific commodity production (so farmers could respond to prevailing market signals) and new marketing options for producers created by the Wheat Board. The PSE for Canada is now comparable to the estimates for the United States and Mexico and well below those for Japan and for the European Union, as well as the OECD average (Agriculture and Agri-Food Canada 2004).

Not all government policy is geared to expanding production. Although farmers have long been admirable stewards of Canada's land and water resources, growing concern that the increase in agricultural output was causing environmental damage prompted governments to focus to a greater extent on improving the environmental performance of Canadian farms and harnessing the resulting benefits. Global pressures related to issues such as climate change, *ozone* depletion, organic pollutants, wildlife habitat and biological diversity have given rise to a number of international initiatives. Furthermore, a wide range of policies and initiatives have been adopted at all levels of government with important implications for Canadian agricultural production and the environment (Table 3-1).

The federal, provincial and territorial Ministers of Agriculture recently developed a five-year (2003-2008) comprehensive Agricultural Policy Framework (APF). The APF is composed of five key elements, one of which involves enhancing the environmental performance of farms across Canada. Specific goals have been set for water supply and water quality, air quality and *soil structure* and biodiversity maintenance. Management goals include the voluntary implementation of environmental farm plans and the adoption of beneficial farm management practices (BMP). Where environmental risks are identified, remedial action is encouraged through targeted incentives for producers to adopt BMPs. Some of the performance targets set under the APF will be measured and reported on using agri-environmental indicators.

With regard to the environment, agriculture remains largely unregulated. However, the overall trend is toward more government intervention, mostly at the provincial and municipal levels. The federal government's role centres on providing agricultural research, funding agri-environmental programs, providing market information, identifying and promoting environmentally beneficial management practices, reforming trade policy and fulfilling Canada's international commitments. To provide farmers with an incentive to meet environmental goals and standards, some countries have made eligibility for farm program support contingent on environmental compliance—a practice known as cross-compliance. Canada's main thrust to date has consisted of voluntary measures and incentives.

■ TECHNOLOGICAL CHANGE

At the farm level, the technological developments of the past 200 years have significantly altered the way in which producers use resources. This is particularly true of the technology explosion that marked the latter part of the 20th century. Noteworthy technological advances of the last 10 to 20 years include new farm implements (e.g. *no-till* seeders), major improvements in information technology and genetic engineering and the advent of precision farming. As well, structural changes have been made in order to exploit economies of scale (e.g. fewer and larger farms, intensive livestock operations). Between 1991 and 2001, the use of no-till methods more than quadrupled (from 7% to 30% of *cultivated land*), producing many positive environmental effects: improved soil quality, reduced erosion, enhanced water quality, reduced greenhouse gas emissions through increased *carbon sequestration* in the soil and enhanced biodiversity. In 2001, 39% of Census farms had a computer to assist with farm management, compared with 11% in 1991. These developments are shifting the emphasis in agriculture away from physical production to activities based more on knowledge and skills. Modern agriculture is characterized by a reduction in physical labour and a move towards specialization, concentration and consolidation. Specialization has spread through entire regions where specific crops are most profitable. The farms in such regions previously supplied a wider range of crops to local markets. Since the prices for specialized crops tend to fluctuate, farmers have also had to adapt by adding value through processing, introducing and developing markets and production practices for new crops, and becoming more involved in crop selling on-line or via market agents. Institutions such as the Wheat Board have had to adapt their selling practices to changing farmer needs and expectations. For most commodities, distance to market is no longer the most important factor in deciding where production should take place. Selecting the right physical and economic environment is a key factor for success in today's competitive world marketplace.

The environmental effects of technological change are the subject of considerable debate. Some technologies have had unanticipated, adverse effects on the environment. For example, the *fumigant* methyl bromide provided benefits for agriculture for a number of years, but its use is being phased out because of negative effects on stratospheric ozone. Once these adverse effects became known, a new driving force for change was created, both to control the widespread use of these chemicals and to search for better alternatives. Looking at the other side of the coin, there are many examples of new technologies and practices that reduce environmental risks, such as biological *pest* control methods, improved manure management systems, more efficient livestock diets and conservation tillage. Biotechnology and genetic engineering potentially offer considerable advantages to farmers for improving crop yields. Herbicide tolerance and insect resistance—the dominant traits of genetically modified crops—can help to increase crop productivity and reduce the use of external inputs such as pesticides. However, in Canada and elsewhere there has been considerable debate about the merits of this technology. Many countries oppose GM products due to the unknown effects on the environment and human health. While farmers do benefit from biotechnology in terms of reduced costs for pest and weed control, consumers are concerned about how GMOs and biotechnology may affect the food products sold in Canada (GlobeScan 2003).

Another emerging technology relates to the use of agricultural feedstocks such as grain and cellulose for the production of biofuels. Rising *fossil fuel* prices, better harvests and lower grain prices have sparked interest in the domestic production of *ethanol* and other biofuels. Some stakeholders see renewable fuels as a way to help achieve Canada's commitment under the Kyoto Protocol to reduce its greenhouse gas emissions (e.g. mandating the use of ethanol blends). The economics of biofuel production and the life cycle impacts on the environment require further study.

■ REFERENCES

Agriculture and Agri-Food Canada, 2004. *Farm Income, Financial Conditions and Government Assistance Data Book*. AAFC, Research and Analysis Directorate, Ottawa (Ont.). www.agr.gc.ca/spb/fiap-dpraa/publications/dbkrdd/2004/sep2004/databook_web_e.pdf

GlobeScan Inc, 2003. *Food Issues Monitor – Canada Tables*. GlobeScan, Toronto (Ont.).

MacGregor, R.J., and T. McRae, 2000. "Driving Forces Affecting the Environmental Sustainability of Agriculture". Chapter 3 in *Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project*, Edited by T. McRae, C.A.S. Smith and L.J. Gregorich. Agriculture and Agri-Food Canada, Ottawa (Ont.). www.agr.gc.ca/env/naharp-pnarsa/ *(Go to related documents)*

STATISTICAL COMPILATION:
Nathan Niu and
Stéphanie Proux

COVERAGE:
National, 2001

4. Overview of Agriculture in Canada

■ CANADA

Land Statistics

Total area	998.5 million ha
Total land area	909.4 million ha
Total farm area	67.5 million ha
Cultivated land	61%
Pastureland	30%
Other land	9%
Average farm area	273 ha

Livestock Population (number of animals)

Poultry	126 million
Cattle & calves	16 million
Pigs	14 million
Dairy cows	1 million

Farm Characteristics

Total number of farms	247,000
Total number of families	188,000
Total number of operators	346,000
Average age of operators	50
Education level of operators	
Postsecondary & university	40%
Grade 9 to 13	48%
Less than grade 9	12%

Farm Income

Total net cash income	$8.1 billion
Total cash receipts	$36.3 billion
Total operating expenses	$28.2 billion
Distribution of farms by revenue class	
Less than $10,000	22%
$10,000 to $49,000	31%
$50,000 to $100,000	14%
More than $100,000	33%

Major Agricultural Outputs

Cattle & calves	$7.9 billion
Dairy	$4.1 billion
Hogs	$3.8 billion
Wheat	$2.5 billion
Poultry & eggs	$2.4 billion
Floriculture & nursery	$1.7 billion
Canola	$1.7 billion
Vegetables	$1.5 billion
Potatoes	$0.7 billion
Corn	$0.6 billion

Food & Beverage Industry

Total number of establishments	6,035
Small (less than 50 employees)	81%
Medium (50 to 199 employees)	14%
Large (more than 200 employees)	5%
Total value of shipments	$70.2 billion
Food manufacturing	$61.6 billion
Meat products	31%
Dairy products	16%
Fruits and vegetables	9%
Grain and oilseed milling	9%
Other food	35%
Beverages	$8.6 billion

International Trade Statistics

Trade balance	$7.4 billion
Exports	
Total agricultural exports	$26.6 billion
Bulk	25%
Intermediate	25%
Consumer-oriented	50%
Major export markets	
United States	$16.6 billion
Japan	$2.4 billion
EU-15	$1.3 billion
Mexico	$0.9 billion
China	$0.8 billion
Imports	
Total agricultural imports	$19.2 billion
Bulk	13%
Intermediate	16%
Consumer oriented	71%
Major import markets	
United States	$12.3 billion
EU-15	$2.4 billion
Australia	$0.6 billion
Mexico	$0.4 billion
New Zealand	$0.4 billion

Contribution to GDP

Agri-food sector	$28.1 billion
Primary agriculture	$6.8 billion
Food processing	$21.3 billion

BRITISH COLUMBIA

Land Statistics

Total area	94.5 million ha
Total land area	92.5 million ha
Total farm area	2.6 million ha
Cultivated land	25%
Pastureland	56%
Other land	19%
Average farm area	128 ha

Livestock Population (number of animals)

Poultry	18.8 million
Cattle & calves	815,000
Pigs	166,000
Dairy cows	71,000

Farm Characteristics

Total number of farms	20,000
Total number of families	15,000
Total number of operators	30,000
Average age of operators	51
Education level of operators	
Postsecondary & University	47%
Grade 9 to 13	45%
Less than grade 9	8%

Farm Income

Total net cash income	$0.4 billion
Total cash receipts	$2.2 billion
Total operating expenses	$1.8 billion
Distribution of farms by revenue class	
Less than $10,000	50%
$10,000 to $49,000	26%
$50,000 to $100,000	7%
More than $100,000	17%

Major Agricultural Outputs

Floriculture & nursery	$394 million
Dairy	$364 million
Cattle & calves	$348 million
Poultry & eggs	$330 million
Vegetables	$293 million

Food & Beverage Industry

Total number of establishments	906
Total value of shipments	$5.5 billion
Food manufacturing	$4.5 billion
Meat products	27%
Seafood products	16%
Dairy products	16%
Animal food products	11%
Other food	30%
Beverages	$1.0 billion

International Trade Statistics

Trade balance	-($1.2 billion)
Exports	
Total agricultural exports	$1.4 billion
Bulk	3%
Intermediate	30%
Consumer-oriented	67%
Major export markets	
United States	$990 million
Japan	$166 million
China	$40 million
Hong Kong	$26 million
Taiwan	$23 million
Imports	
Total agricultural imports	$2.6 billion
Bulk	8%
Intermediate	13%
Consumer-oriented	79%

■ ALBERTA

Land Statistics

Total area	66.2 million ha
Total land area	64.2 million ha
Total farm area	21.1 million ha
Cultivated land	52%
Pastureland	42%
Other land	6%
Average farm area	393 ha

Livestock Population (number of animals)

Poultry	12.2 million
Cattle & calves	6.6 million
Pigs	2.0 million
Dairy cows	84,000

Farm Characteristics

Total number of farms	54,000
Total number of families	41,000
Total number of operators	76,000
Average age of operators	50
Education level of operators	
Postsecondary & university	42%
Grade 9 to 13	50%
Less than grade 9	8%

Farm Income

Total net cash income	$1.9 billion
Total cash receipts	$8.4 billion
Total operating expenses	$6.4 billion
Distribution of farms by revenue class	
Less than $10,000	19%
$10,000 to $49,000	33%
$50,000 to $100,000	16%
More than $100,000	32%

Major Agricultural Outputs

Cattle & Calves	$3.9 billion
Wheat	$691 million
Canola	$586 million
Hogs	$572 million
Dairy	$348 million

Food & Beverage Industry

Total number of establishments	551
Total value of shipments	$9.3 billion
Food manufacturing	$8.4 billion
Meat products	61%
Dairy products	10%
Grain and oilseed milling	9%
Animal food products	7%
Other food	13%
Beverages	$0.9 billion

International Trade Statistics

Trade balance	$4.7 billion
Exports	
Total agricultural exports	$6.0 billion
Bulk	30%
Intermediate	30%
Consumer-oriented	40%
Major export markets	
United States	$3.2 billion
Japan	$781 million
Mexico	$410 million
China, People's Republic of	$281 million
Iran	$133 million
Imports	
Total agricultural imports	$1.2 billion
Bulk	7%
Intermediate	23%
Consumer-oriented	70%

SASKATCHEWAN

Land Statistics

Total area	65.1 million ha
Total land area	59.2 million ha
Total farm area	26.3 million ha
Cultivated land	70%
Pastureland	25%
Other land	5%
Average farm area	519 ha

Livestock Population (number of animals)

Poultry	4.7 million
Cattle & calves	2.9 million
Pigs	1.1 million
Dairy cows	30,000

Farm Characteristics

Total number of farms	51,000
Total number of families	39,000
Total number of operators	66,000
Average age of operators	50
Education level of operators	
Postsecondary & university	36%
Grade 9 to 13	51%
Less than grade 9	12%

Farm Income

Total net cash income	$1.8 billion
Total cash receipts	$6.5 billion
Total operating expenses	$4.7 billion
Distribution of farms by revenue class	
Less than $10,000	13%
$10,000 to $49,000	32%
$50,000 to $100,000	20%
More than $100,000	35%

Major Agricultural Outputs

Wheat	$1.3 billion
Cattle & calves	$1.2 billion
Canola	$749 million
Barley	$301 million
Hogs	$233 million

Food & Beverage Industry

Total number of establishments	169
Total value of shipments	$1.9 billion
Food manufacturing	$1.8 billion
Meat products	42%
Grain and oilseed milling	32%
Animal food products	10%
Other food	16%
Beverages	$74 million

International Trade Statistics

Trade balance	$4.2 billion
Exports	
Total agricultural exports	$4.5 billion
Bulk	70%
Intermediate	26%
Consumer-oriented	4%
Major export markets	
United States	$1.1 billion
Japan	$508 million
China	$343 million
Mexico	$253 million
Iran	$195 million
Imports	
Total agricultural imports	$287 million
Bulk	13%
Intermediate	33%
Consumer-oriented	54%

■ MANITOBA

Land Statistics

Total area	64.8 million ha
Total land area	55.4 million ha
Total farm area	7.6 million ha
Cultivated land	65%
Pastureland	26%
Other land	9%
Average farm area	361 ha

Livestock Population (number of animals)

Poultry	8.0 million
Pigs	2.5 million
Cattle & calves	1.4 million
Dairy cows	42,000

Farm Characteristics

Total number of farms	21,000
Total number of families	16,000
Total number of operators	29,000
Average age of operators	49
Education level of operators	
Postsecondary & university	34%
Grade 9 to 13	52%
Less than grade 9	14%

Farm Income

Total net cash income	$0.9 billion
Total cash receipts	$3.7 billion
Total operating expenses	$2.8 billion
Distribution of farms by revenue class	
Less than $10,000	18%
$10,000 to $49,000	29%
$50,000 to $100,000	17%
More than $100,000	37%

Major Agricultural Outputs

Hogs	$806 million
Cattle & calves	$570 million
Wheat	$455 million
Canola	$364 million
Dairy	$158 million

Food & Beverage Industry

Total number of establishments	207
Total value of shipments	$2.7 billion
Food manufacturing	$2.4 billion
Meat products	39%
Animal food products	14%
Grain and oilseed milling	11%
Other food	36%
Beverages	$212 million

International Trade Statistics

Trade balance	$2.3 billion
Exports	
Total agricultural exports	$3.0 billion
Bulk	43%
Intermediate	33%
Consumer-oriented	24%
Major export markets	
United States	$1.5 billion
Japan	$427 million
Mexico	$171 million
China	$142 million
Iran	$89 million
Imports	
Total agricultural imports	$734 million
Bulk	15%
Intermediate	28%
Consumer-oriented	57%

■ ONTARIO

Land Statistics

Total area	107.6 million ha
Total land area	91.8 million ha
Total farm area	5.5 million ha
Cultivated land	67%
Pastureland	16%
Other land	17%
Average farm area	92 ha

Livestock Population (number of animals)

Poultry	44 million
Pigs	3.5 million
Cattle & calves	2.1 million
Dairy cows	364,000

Farm Characteristics

Total number of farms	60,000
Total number of families	47,000
Total number of operators	85,000
Average age of operators	51
Education level of operators	
Postsecondary & University	42%
Grade 9 to 13	45%
Less than grade 9	14%

Farm Income

Total net cash income	$1.6 billion
Total cash receipts	$8.5 billion
Total operating expenses	$6.9 billion
Distribution of farms by revenue class	
Less than $10,000	26%
$10,000 to $49,000	32%
$50,000 to $100,000	11%
More than $100,000	31%

Major Agricultural Outputs

Dairy	$1.4 billion
Cattle & calves	$1.3 billion
Hogs	$946 million
Floriculture & nursery	$842 million
Poultry & eggs	$833 million

Food & Beverage Industry

Total number of establishments	1,932
Total value of shipments	N/A
Food manufacturing	$24.5 billion
Meat products	24%
Dairy products	15%
Fruits and vegetables	13%
Grain and oilseed milling	13%
Other food	36%
Beverages	N/A

International Trade Statistics

Trade balance	-($3.3 billion)
Exports	
Total agricultural exports	$7.8 billion
Bulk	6%
Intermediate	21%
Consumer-oriented	73%
Major export markets	
United States	$6.7 billion
Japan	$218 million
Hong Kong	$135 million
United Kingdom	$107 million
Germany	$64 million
Imports	
Total agricultural imports	$11.1 billion
Bulk	13%
Intermediate	15%
Consumer-oriented	72%

■ QUEBEC

Land Statistics

Total area	154.2 million ha
Total land area	136.5 million ha
Total farm area	3.4 million ha
Cultivated land	54%
Pastureland	11%
Other land	35%
Average farm area	106 ha

Livestock Population (number of animals)

Poultry	29.2 million
Pigs	4.3 million
Cattle & calves	1.4 million
Dairy cows	407,000

Farm Characteristics

Total number of farms	32,000
Total number of families	23,000
Total number of operators	47,000
Average age of operators	47
Education level of operators	
Postsecondary & university	37%
Grade 9 to 13	44%
Less than grade 9	18%

Farm Income

Total net cash income	$1.3 billion
Total cash receipts	$5.8 billion
Total operating expenses	$4.5 billion
Distribution of farms by revenue class	
Less than $10,000	17%
$10,000 to $49,000	27%
$50,000 to $100,000	13%
More than $100,000	44%

Major Agricultural Outputs

Dairy	$1.5 billion
Hogs	$1.1 billion
Poultry & eggs	$588 million
Cattle & calves	$533 million
Vegetables	$282 million

Food & Beverage Industry

Total number of establishments	1,481
Total value of shipments	N/A
Food manufacturing	$14.2 billion
Meat products	32%
Dairy products	23%
Fruits and vegetables	6%
Other food	38%
Beverages	N/A

International Trade Statistics

Trade balance	$0.4 billion
Exports	
Total agricultural exports	$3.2 billion
Bulk	4%
Intermediate	15%
Consumer-oriented	82%
Major export markets	
United States	$2.4 billion
Japan	$211 million
Mexico	$41 million
Cuba	$40 million
France	$33 million
Imports	
Total agricultural imports	$2.8 billion
Bulk	20%
Intermediate	16%
Consumer-oriented	64%

■ NEW BRUNSWICK

Land Statistics

Total area	7.3 million ha
Total land area	7.1 million ha
Total farm area	388,000 ha
Cultivated land	39%
Pastureland	12%
Other land	50%
Average farm area	128 ha

Livestock Population (number of animals)

Poultry	3.5 million
Pigs	137,000
Cattle & calves	91,000
Dairy cows	19,000

Farm Characteristics

Total number of farms	3,034
Total number of families	2,260
Total number of operators	3,900
Average age of operators	51
Education level of operators	
Postsecondary & university	40%
Grade 9 to 13	44%
Less than grade 9	16%

Farm Income

Total net cash income	$72 million
Total cash receipts	$412 million
Total operating expenses	$340 million
Distribution of farms by revenue class	
Less than $10,000	39%
$10,000 to $49,000	28%
$50,000 to $100,000	8%
More than $100,000	26%

Major Agricultural Outputs

Potatoes	$100 million
Dairy	$68 million
Poultry & eggs	$65 million
Floriculture & nursery	$46 million
Hogs	$38 million

Food & Beverage Industry

Total number of establishments	199
Total value of shipments	$2.1 billion
Food manufacturing	$1.9 billion
Seafood products	45%
Dairy products	7%
Animal food products	6%
Bakeries and tortilla products	3%
Other food	39%
Beverages	$210 million

International Trade Statistics

Trade balance	$119 million
Exports	
Total agricultural exports	$378 million
Bulk	0%
Intermediate	9%
Consumer-oriented	91%
Major export markets	
United States	$308 million
Japan	$30 million
Philippines	$6 million
Venezuela	$5 million
Taiwan	$5 million
Imports	
Total agricultural imports	$259 million
Bulk	11%
Intermediate	14%
Consumer-oriented	75%

■ NOVA SCOTIA

Land Statistics

Total area	5.5 million ha
Total land area	5.3 million ha
Total farm area	407,000 ha
Cultivated land	29%
Pastureland	14%
Other land	57%
Average farm area	104 ha

Livestock Population (number of animals)

Poultry	4.1 million
Pigs	125,000
Cattle & calves	108,000
Dairy cows	24,000

Farm Characteristics

Total number of farms	3,923
Total number of families	3,025
Total number of operators	5,070
Average age of operators	51
Education level of operators	
Postsecondary & university	52%
Grade 9 to 13	39%
Less than grade 9	9%

Farm Income

Total net cash income	$70 million
Total cash receipts	$421 million
Total operating expenses	$351 million
Distribution of farms by revenue class	
Less than $10,000	40%
$10,000 to $49,000	32%
$50,000 to $100,000	7%
More than $100,000	22%

Major Agricultural Outputs

Dairy	$96 million
Poultry & eggs	$86 million
Hogs	$39 million
Floriculture & nursery	$35 million
Cattle & calves	$34 million

Food & Beverage Industry

Total number of establishments	323
Total value of shipments	N/A
Food manufacturing	$2.0 billion
Seafood products	43%
Other food	22%
Dairy products	16%
Meat products	13%
Animal food products	6%
Beverages	N/A

International Trade Statistics

Trade balance	$6 million
Exports	
Total agricultural exports	$174 million
Bulk	0%
Intermediate	8%
Consumer-oriented	92%
Major export markets	
United States	$130 million
Japan	$11 million
Germany	$10 million
United Kingdom	$5 million
France	$3 million
Imports	
Total agricultural imports	$180 million
Bulk	42%
Intermediate	3%
Consumer-oriented	56%

■ PRINCE EDWARD ISLAND

Land Statistics

Total area	566,000 ha
Total land area	566,000 ha
Total farm area	261,000 ha
Cultivated land	67%
Pastureland	9%
Other land	23%
Average farm area	142 ha

Livestock Population (number of animals)

Poultry	365,000
Pigs	126,000
Cattle & calves	85,000
Dairy cows	15,000

Farm Characteristics

Total number of farms	1,845
Total number of families	1,425
Total number of operators	2,455
Average age of operators	49
Education level of operators	
Postsecondary & university	41%
Grade 9 to 13	47%
Less than grade 9	12%

Farm Income

Total net cash income	$45 million
Total cash receipts	$337 million
Total operating expenses	$292 million
Distribution of farms by revenue class	
Less than $10,000	19%
$10,000 to $49,000	28%
$50,000 to $100,000	13%
More than $100,000	40%

Major Agricultural Outputs

Potatoes	$124 million
Dairy	$52 million
Hogs	$34 million
Cattle & calves	$28 million
Vegetables	$10 million

Food & Beverage Industry

Total number of establishments	88
Total value of shipments	N/A
Food manufacturing	$859 million
Seafood products	34%
Other food	66%
Beverages	N/A

International Trade Statistics

Trade balance	$285 million
Exports	
Total agricultural exports	$288 million
Bulk	0%
Intermediate	1%
Consumer-oriented	99%
Major export markets	
United States	$265 million
Venezuela	$4 million
Trinidad-Tobago	$4 million
Uruguay	$2 million
Barbados	$1 million
Imports	
Total agricultural imports	$3 million
Bulk	8%
Intermediate	16%
Consumer-oriented	76%

■ NEWFOUNDLAND AND LABRADOR

Land Statistics

Total area	40.5 million ha
Total land area	37.4 million ha
Total farm area	41,000 ha
Cultivated land	21%
Pastureland	24%
Other land	55%
Average farm area	60 ha

Livestock Population (number of animals)

Poultry	1.7 million
Cattle & calves	9,000
Dairy cows	5,000
Pigs	3,000

Farm Characteristics

Total number of farms	643
Total number of families	430
Total number of operators	790
Average age of operators	51
Education level of operators	
Postsecondary & university	46%
Grade 9 to 13	37%
Less than grade 9	16%

Farm Income

Total net cash income	$8 million
Total cash receipts	$79 million
Total operating expenses	$71 million
Distribution of farms by revenue class	
Less than $10,000	45%
$10,000 to $49,000	28%
$50,000 to $100,000	8%
More than $100,000	20%

Major Agricultural Outputs

Dairy	$27 million
Poultry & eggs	$10 million
Floriculture & nursery	$10 million
Vegetables	$3 million
Cattle & calves	$2 million

Food & Beverage Industry

Total number of establishments	179
Total value of shipments	N/A
Food manufacturing	$1 million
Seafood products	81%
Other food	19%
Beverages	N/A

International Trade Statistics

Trade balance	-($14 million)
Exports	
Total agricultural exports	$1 million
Bulk	0%
Intermediate	12%
Consumer-oriented	88%
Major export markets	
United States	$410,000
United Kingdom	$290,000
Germany	$250,000
Russia	$140,000
St. Pierre-Miquelon	$110,000
Imports	
Total agricultural imports	$15 million
Bulk	0%
Intermediate	1%
Consumer-oriented	99%

■ DATA SOURCES

The main source for statistics on land use, livestock populations, farm characteristics and farm income is: Statistics Canada, 2001. *Census of Agriculture.*

Major agricultural outputs: Statistics Canada, 2001. *Farm Cash Receipts.*

Food and beverage industry: Statistics Canada, 2001. *Annual Survey of Manufactures.*

International trade, import and export markets, contribution to GDP: Statistics Canada, 2001. *Canadian International Merchandise Trade Database.*

Note: Some provincial data on the agriculture and agri-food sector are underreported owing to data confidentiality or gaps in the data. As a result, provincial totals may not add up to the values reported for Canada as a whole.

5. Linking Science to Policy

AUTHOR:
B. Junkins

SUMMARY

Understanding how changes to agricultural polices and programs will impact the sector's future economic and environmental outcomes is critical for the policy development and evaluation process. Achieving this insight necessitates linking science to analytical policy tools. Agriculture and Agri-Food Canada (AAFC) has used a multidisciplinary approach to develop this kind of integrated modelling capacity by linking the Canadian Regional Agricultural Model (CRAM), a policy model, to agri-environmental indicators. In recent years, this science-based analytical approach has proven very useful for agricultural policy analysis, for example to assess possible greenhouse gas (GHG) mitigation strategies and to support the selection of quantitative environmental performance targets under the Agricultural Policy Framework (APF). While the demand for this type of analysis is increasing, many methodological issues still need to be ironed out.

INTRODUCTION

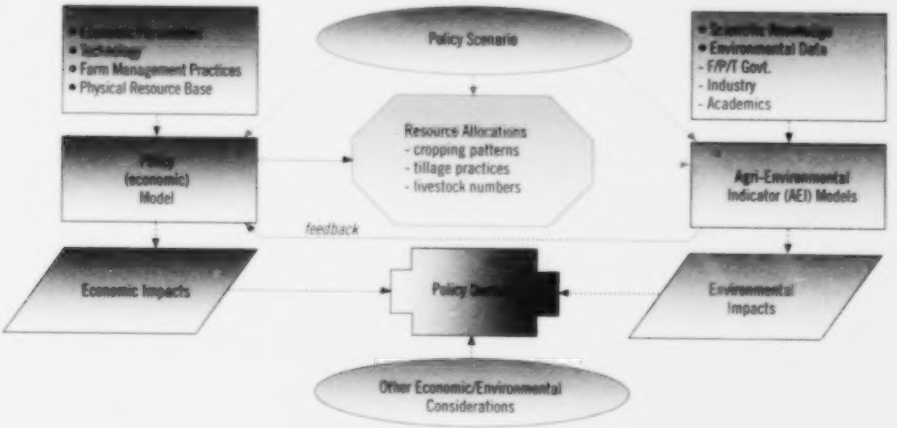
Agri-environmental indicators (AEI) provide a historical perspective on the agriculture sector's environmental performance. However, in order for the sector to manage its natural resources in a manner that is environmentally, socially and economically sustainable, there is a need to understand how changes to agricultural polices and programs will affect the sector's economic and environmental outcomes and how to produce outcomes that are consistent with government goals and objectives. Science must be harnessed in the policy development process to generate reliable quantitative information about environmental effects and support analytical tools that allow this information to be integrated into the policy decision-making process. In the present context, this involves integrating agri-environmental indicator models with policy models. Such integrated models can then be used to evaluate existing policies and programs relative to their combined economic and environmental performance, as well as to estimate or predict the economic and environmental impacts of proposed programs and policies.

LINKING AGRI-ENVIRONMENTAL INDICATORS TO POLICY MODELS

Building this type of integrated modelling capacity requires a multidisciplinary approach involving both research scientists and economists. The integrated economic/environmental modelling system under development at AAFC uses a policy model to estimate changes in farm resource allocations (crops and livestock) relative to a baseline level for selected scenarios and feeds this information into AEI models to assess a suite of potential environmental outcomes (Figure 5-1). The economic model used is the Canadian Regional Agricultural Model (CRAM) (Horner at al. 1992). It is capable of estimating the change in resource allocations for various crop and livestock activities in response to changes in technology, government programs and policies or market conditions.

This integrated economic/environmental modelling approach was first developed to enable AAFC to estimate the economic and environmental consequences of wind and water erosion on the Prairies (Bouzaher et al. 1995). AAFC subsequently enhanced the methodology and used it to assess erosion impacts following the elimination of the Western Grain Transportation Act (WGTA) subsidy and the reform of the Canadian Wheat

Figure 5-1: Integrated economic/environmental analysis

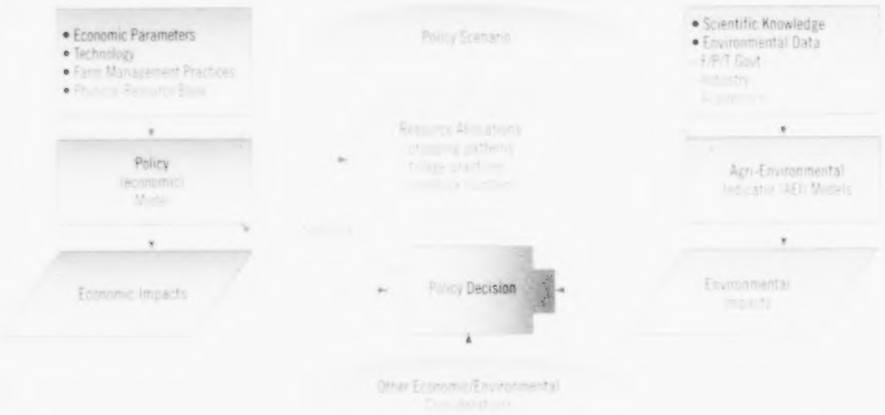

• Economic Parameters
• Technology
• Farm Management Practices
• Physical Resource Base
Policy Scenario
• Scientific Knowledge
• Environmental Data
- F/P/T Govt.
- Industry
- Academics
Policy (economic) Model
Resource Allocations
- cropping patterns
- tillage practices
- livestock numbers
Agri-Environmental Indicator (AEI) Models
feedback
Economic Impacts
Policy Decision
Environmental Impacts
Other Economic/Environmental Considerations

Board (CWB) pooling regime, as well as for an environmental assessment of the Federal-Provincial Crop Insurance Program across Canada (MacGregor et al. 1998).

In recent years, a lot of work has gone into developing the Canadian Economic and Emissions Model for Agriculture (CEEMA) (Kulshreshtha et al. 2002) by linking CRAM to the greenhouse gas indicator (see Chapter 21). CEEMA has been used in the following contexts: the analysis of possible GHG mitigation strategies in support of the work of the Agriculture and Agri-Food Climate Change Table (National Climate Change Secretariat-Agriculture and Agri-Food Table 2000); the development of GHG mitigation programs for agriculture; international negotiations (UNFCCC 2000); and the development of a national climate change plan for Canada. Results from the integrated economic/environmental analysis of GHG mitigation options for agriculture were instrumental in getting agricultural soil sinks accepted under the Kyoto Protocol.

More recently, a study was initiated to use an integrated economic/environmental modelling system to support the selection of quantitative provincial environmental outcome goals and targets under the Environment Chapter of the Agricultural Policy Framework (APF) (Heigh et al. 2005). The system was able to model the environmental effects associated with the adoption of a suite of beneficial management practices (BMPs) for agricultural production in Canada. The quantification encompassed the impact of various soil, pasture, nutrient and livestock management practices and agroforestry activities on air, soil and water quality, as well as on biodiversity indicators. The analysis was limited to existing AEI models with national coverage that could be linked to CRAM (water and wind erosion, residual soil nitrogen, IROWC-N, greenhouse gases, soil carbon and wildlife habitat). The study also assisted in identifying appropriate environmental goals by providing an indication of the range of achievable outcomes based on three potential adoption rates for each BMP. The findings have been used in consultations with the provinces to set quantitative environmental outcome targets in the APF Implementation Agreements.

Figure 5-1: Integrated economic/environmental analysis


• Economic Parameters
• Technology
• Farm Management Practices
• Physical Resource Base
Policy Scenario
• Scientific Knowledge
• Environmental Data
- F/P/T Govt
- Industry
- Academia
Policy
(economic)
Model
Resource Allocations
(cropping patterns
tillage practices
livestock numbers)
Agri-Environmental
Indicator (AEI) Models
Feedback
Economic Impacts
Policy Decision
Environmental
Impacts
Other Economic/Environmental
Considerations

Board (CWB) pooling regime, as well as for an environmental assessment of the Federal-Provincial Crop Insurance Program across Canada (MacGregor et al. 1998).

In recent years, a lot of work has gone into developing the Canadian Economic and Emissions Model for Agriculture (CEEMA) (Kulshreshtha et al. 2002) by linking CRAM to the greenhouse gas indicator (see Chapter 21). CEEMA has been used in the following contexts: the analysis of possible GHG mitigation strategies in support of the work of the Agriculture and Agri-Food Climate Change Table (National Climate Change Secretariat-Agriculture and Agri-Food Table 2000); the development of GHG mitigation programs for agriculture; international negotiations (UNFCCC 2000); and the development of a national climate change plan for Canada. Results from the integrated economic/environmental analysis of GHG mitigation options for agriculture were instrumental in getting agricultural soil sinks accepted under the Kyoto Protocol.

More recently, a study was initiated to use an integrated economic/environmental modelling system to support the selection of quantitative provincial environmental outcome goals and targets under the Environment Chapter of the Agricultural Policy Framework (APF) (Heigh et al. 2005). The system was able to model the environmental effects associated with the adoption of a suite of beneficial management practices (BMPs) for agricultural production in Canada. The quantification encompassed the impact of various soil, pasture, nutrient and livestock management practices and agroforestry activities on air, soil and water quality, as well as on biodiversity indicators. The analysis was limited to existing AEI models with national coverage that could be linked to CRAM (water and wind erosion, residual soil nitrogen [ROWC-N], greenhouse gases, soil carbon and wildlife habitat). The study also assisted in identifying appropriate environmental goals by providing an indication of the range of achievable outcomes based on three potential adoption rates for each BMP. The findings have been used in consultations with the provinces to set quantitative environmental outcome targets in the APF Implementation Agreements.

LIMITATIONS AND FUTURE DIRECTIONS

Analytical models based on sound science have proven very useful for policy evaluation and development purposes, and the demand for this type of analysis is increasing. However, this is groundbreaking work. Development of the analytical capacity has just begun and there are still many unresolved issues related to resources, data, models, science and spatial aspects. Some of the main limitations in terms of the current capacity to do this type of integrated modelling, as well as future directions envisaged for this work, are described below.

As a policy tool, the Canadian Regional Agricultural Model (CRAM) is based on political boundaries that are dictated by the available economic data (22 crop production regions in the Prairies, provincial basis for crops in other regions and for livestock). Yet, environmental issues are inherently local in nature, which is why agri-environmental indicators are based on much smaller ecological regions (Soil Landscape of Canada (SLC) polygons). Consequently, the output from CRAM needs to be broken down to the SLC level so that the cropping and management practice scenarios from the policy model can be assigned to specific locations within the landscape. At present, this is done by assuming a uniform distribution. Work is under way to improve this aspect of the analytical system through developing a Land Use Allocation Model (LUAM), which would predict spatially explicit land use change based on factors such as attributes of the land that affect its resilience/suitability (soils, topography, climate), competing land use demands, proximity to markets, production costs, existing land use and its adaptability to change.

Analytical models based on sound science have proven very useful for policy evaluation and development purposes, and the demand for this type of analysis is increasing.

The scenarios and agri-environmental indicators that have been used in the analyses to date are constrained by the availability of integrated models. As a result, some important farm management options (e.g. manure management) are left out of the analyses. Similarly, quantitative assessments of the "on-farm" economic impacts of environmental management scenarios are limited by the lack of relevant economic information. For many scenarios, informed assumptions about BMP adoption rates have been imposed, and so the results are not driven by the underlying economics of the policy model. Finally, the existing integrated modelling system does not include any feedback linkages between the economic and environmental components in the sense that outputs from policy model scenarios are used as input to the AEI models to estimate the environmental impacts, but not vice versa (changes in environmental indicators could have economic consequences).

Development of integrated modelling capacity and of applications for policy analysis is an ongoing process. A revised version of CRAM, which is currently being tested, incorporates a number of improvements, such as the addition of an agricultural water demand component and the division of Ontario, Quebec and British Columbia into multiple regions. Studies are also planned on the farm-level costs and benefits of adopting environmentally friendly BMPs, and the information that is obtained will be fed into CRAM to enhance economic analysis for selected scenarios. Since the existing AEI models are being updated and new ones developed, linkages between CRAM and the AEIs will require ongoing adjustment. In the future, an estimate of the level of uncertainty associated with model results will be required for informed policy decision making.

Integrated economic/environmental models provide the capacity to estimate the environmental impacts of agricultural programs and policies in physical terms (e.g. soil erosion in tonnes/ha/yr or greenhouse gas emissions in tonnes/yr), as well as the economic consequences for producers. However, to permit a complete cost-benefit analysis, a monetary value must first be assigned to these environmental impacts and a trade-off analysis of the economic and environmental outcomes can then be performed.

There is increasing demand for this type of integrated analysis among policy makers. Ongoing and future applications of the integrated economic/environmental modelling system include the following: refining the environmental outcome targets of the APF and evaluating new technologies and the next generation of BMPs for the next version of the APF; tackling climate change by developing a domestic emissions trading (DET) and offsets system, analysing a more aggressive set of mitigation options including environmental co-benefits and assessing the impacts of climate change on the agriculture sector along with possible adaptation strategies; and carrying out environmental assessments of agricultural policies and programs (e.g. World Trade Organization negotiations).

■ REFERENCES

Bouzaher, A., J.F. Shogren, D. Holtkamp, P. Gassman, D Archer, P. Lakshminarayan, A. Carriquiry, R. Reese, D. Kakani, W.H. Furtan, R.C. Izaurralde, and J. Kiniry, 1996. *Agricultural Policies and Soil Degradation in Western Canada: An Agro-Ecological Economic Assessment. Report 5: Project Summary.* Technical Report No. 2-95. Agriculture and Agri-Food Canada, Ottawa (Ont.).

Heigh, L., B. Junkins, R.J. MacGregor, R. Gill, J. Heigh, T. Huffman, J. Yang, L. van Vliet, G. Padbury, and M. Boehm, 2004. *Quantitative Analysis of the Impact of Agricultural Management Strategies on Environmental Indicators.* Agriculture and Agri-Food Canada, Ottawa (Ont.). www.agr.gc.ca/spb/rad-dra/publications/isie/ise_e.pdf

Horner, G.L., J. Corman, R.E. Howitt, C.A. Carter, and R.J. MacGregor, 1992. *The Canadian Regional Agriculture Model Structure, Operation and Development.* Agriculture and Agri-Food Canada, Ottawa (Ont.).

Kulshreshtha, S.N., R. Gill, B. Junkins, R. Desjardins, M. Boehm and M. Bonneau, 2002. *Canadian Economic and Emissions Model for Agriculture (C.E.E.M.A. 2.0): Technical Documentation.* CSALE Working Paper #12. University of Saskatchewan, Saskatoon (Sas.). www.csale.usask.ca/PDFDocuments/cndEconEmissionMdl.pdf

MacGregor, R.J., J. Giraldez, I. Campbell, G. Wall, B. Junkins, R. Gill, I. Shelton, B. Stephen, and G. Padbury, 1998. *The Federal-Provincial Crop Insurance Program: An Integrated Environmental-Economic Assessment.* Agriculture and Agri-Food Canada, Ottawa (Ont.). www.agr.gc.ca/spb/rad-dra/publications/fedprov/fedprov_e.php

National Climate Change Secretariat-Agriculture and Agri-Food Table, 2000. *Options Report: Reducing Greenhouse Gas Emissions from Canadian Agriculture. Agriculture and Agri-Food Climate Change Table.* Agriculture and Agri-Food Canada, Ottawa (Ont.). http://dsp-psd.pwgsc.gc.ca/Collection/M22-132-1-2000E.pdf

United Nations Framework Convention on Climate Change (UNFCCC), 2000. *Proposals Related to Kyoto Protocol Articles 3.3 and 3.4.* Paper No. 3, pp. 46-104. UNFCCC Secretariat, Subsidiary Body for Scientific and Technological Advice (SBSTA), Lyon (France). http://unfccc.int/resource/docs/2000/sbsta/misc06.pdf

Environmental Farm Management

B

6. Agriculture Land Use Change

AUTHORS:
W. Eilers and
T. Huffman

INFORMATION SOURCE:
Census of Agriculture

STATUS:
National coverage, 1981 to 2001

■ SUMMARY

Over the 20-year period from 1981 to 2001, agricultural land use intensity increased across Canada. Noteworthy developments in Western Canada include a marked decline in the area of summerfallow, an increase in the area of forages and expanded use of soil-conserving practices for tillage as well as summerfallow. Diversification of cropping has been a prominent feature of the changing situation of land use in the West, particularly on the Prairies, and this is evidenced by a decrease in the area of the more traditional cereal grains and an increase in the area of oilseed and pulse crops. In Eastern Canada, whereas the overall amount of farmland decreased during the 20-year period under review, the area of cropped land actually increased in every province. In general, this expansion in the area of cropland occurred at the expense of pasture and summerfallow.

■ THE ISSUE

The idea of using agri-environmental indicators to track changes in a broad and varied industry like agriculture arose because of the impracticality of repeatedly measuring a wide range of specific conditions across all the agricultural landscapes of Canada. The development of science-based agri-environmental indicators is predicated on applying current scientific knowledge to understanding the effects that a limited number of key land use and management practices have on the environment. Trends in such key variables are assessed over time and interpreted with reference to individual indicators. As an example, within the farmland sphere, different crops and land use types have differing propensities for creating conditions that are conducive to soil erosion. A shift toward increasing area under row crops, such as potatoes or corn, or under summerfallow, generally indicates movement toward higher erosion risk, whereas an increase in the area of hay crops signals a lower risk of erosion. The risk level may be altered, that is, either increased or decreased, by the specific management practices that are applied.

This chapter presents some of the key adjustments in land use and agricultural management practices that occurred between 1981 and 2001 in Canada based on an evaluation of data from the Census of Agriculture. This national survey conducted by Statistics Canada every five years encompasses a wide variety of variables and ensures consistent coverage of all farms. It therefore has tremendous potential as a tool for assessing changes in land use trends at the provincial and national levels. The types of environmental impacts these changes have generated are captured and explored in the agri-environmental indicator chapters presented in this report.

■ LAND USE INFORMATION

Within the farmland sphere, different crops and land use types have different propensities for causing environmental impacts. To present an overview of long-term trends in land use for the individual provinces and nationally, six key Census variables have been used:

1) Area of farmland
2) Area of cultivated farmland
3) Area of pasture (improved pasture and native pasture)
4) Area of row crops (corn for grain and silage, vegetables, potatoes, tobacco)
5) Area of summerfallow
6) Area of "other land," or the area of farmland devoted to uses other than crops or livestock (e.g. farm buildings, barnyards, greenhouses, woodlots, *windbreaks*, marshes).

CROPPING PRACTICES

In addition to land use information, it is important to know the types and trends in crops that are typically grown in the regions, because different cropping patterns typically have differing effects on the environment. Seven key Census crop type variables are used:

1) Area of annually cropped land (land used to produce crops, excluding summerfallow and pasture);

2) Area of cereal crops (wheat, barley, oats);

3) Area of oilseeds (canola, mustard, flax, safflower, sunflower);

4) Area of corn (grain corn, silage corn);

5) Area of potatoes;

6) Area of pulse crops and legumes (beans, lentils, chick peas, dry field peas);

7) Area of *forage* crops (alfalfa and alfalfa mixes, other tame hay and fodder crops cut for hay or silage, forage harvested for seed).

TILLAGE PRACTICES

As noted earlier, the management practices employed by farmers need to be considered in interpreting land use trends. Tillage practices have been evaluated in the Census of Agriculture since 1991 using six different variables:

1) Area of cropland prepared for seeding using *conventional tillage* practices (tillage that turns over the top 15 to 20 cm of soil, burying plant residues and exposing the soil, followed by secondary tillage to break up soil aggregates and produce a smooth, even seedbed);

2) Area of land prepared for seeding using *conservation tillage* (tillage practices that break up the soil and kill weeds but do not turn the soil over);

3) Area of land prepared for seeding using no-till (management practice that maintains all plant residues on the surface);

4) Area of summerfallow maintained by tillage weed control (the practice of fallowing traditionally required that tillage be carried out periodically during the growing season);

5) Area of summerfallow maintained by a combination of chemical and tillage weed control (chemical and tillage weed control reduces the amount of tillage involved in weed control, through either reduced-frequency tillage or "spot cultivation");

6) Area of summerfallow maintained by chemical-only weed control.

LIMITATIONS

The main limitations relating to the numbers reported in this chapter consist of the possibility that producers misinterpreted the Census questions and changes in the questions over time. For example, according to Statistics Canada (1997), in 1981, the area of unimproved land was underreported in the four western provinces. This affected the area of total farmland and all "other land" categories for each of the western provinces and for Canada as a whole. Also producers may have had difficulty with interpretation of the terms for different types of tillage practices. This may have influenced the areas reported. A more complete description of potential errors and data quality is provided in Statistics Canada (1997).

OBSERVED TRENDS

National and provincial land use trends, derived from Statistics Canada's Census of Agriculture, are provided in Tables 6-1, 6-2 and 6-3 for Census years 1981 through 2001 (except for tillage data which are available only for 1991, 1996 and 2001).

Canada: The total amount of farmland in Canada remained relatively stable between 1981 (65.9 million ha) and 2001 (67.5 million ha), largely because the vast majority of land that is suitable for agriculture is already being used for that purpose. For similar reasons, the proportions of cultivated farmland (61%), pasture (30%), row crops (3%) and "other land" (9%) also remained fairly constant.

Table 6-1: Agricultural land use, 1981 to 2001

Share of Farmland in Various Uses (in %)

	Major Land Use Categories															Specific Land Use Examples									
Province	**Cultivated**					**Pasture**					**Other Land**					**Summerfallow**					**Row Crops**				
	81	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**
BC	29	27	26	24	26	59	51	53	56	56	12	22	21	20	19	3	3	2	2	1	1	1	1	1	1
AB	56	55	53	52	52	40	38	40	41	42	4	7	6	7	6	12	10	9	7	6	<1	<1	<1	<1	<1
SK	71	71	71	71	70	27	24	24	24	25	2	5	5	5	5	26	21	21	17	12	<1	<1	<1	<1	<1
MB	66	65	65	65	65	29	26	27	26	26	5	9	7	9	9	8	7	4	4	3	2	1	1	1	1
ON	61	63	64	64	67	24	19	19	18	15	15	19	17	19	17	1	1	1	<1	<1	21	18	18	18	19
QC	48	49	48	51	55	21	17	19	15	11	31	34	33	34	35	1	1	<1	<1	<1	8	10	11	13	16
NB	31	33	33	36	39	20	14	16	13	12	49	53	52	52	50	1	1	<1	<1	<1	6	6	7	7	7
NS	25	27	27	29	32	20	16	17	14	14	55	56	56	59	57	1	1	<1	<1	<1	2	2	2	2	3
PEI	57	58	60	64	67	18	14	14	10	10	25	28	27	25	24	1	1	<1	<1	<1	11	11	13	18	18
NL	15	14	14	17	22	64	34	39	21	24	21	52	47	62	55	1	1	<1	<1	<1	3	2	2	2	2
Canada	**62**	**61**	**61**	**61**	**61**	**31**	**28**	**30**	**29**	**30**	**7**	**10**	**9**	**10**	**9**	**15**	**13**	**12**	**9**	**7**	**3**	**2**	**2**	**2**	**3**

Nationally, the amount of farmland under summerfallow decreased by more than half between 1981 and 2001, from 15% to 7%. There are several reasons for this, including the adoption of management practices that make more efficient use of available moisture and allow *continuous cropping* or extended *crop rotations* under rainfed agriculture; the availability of suitable and affordable chemical weed-control options; and the conversion of marginal land to *permanent cover* or pasture. The downturn in the area of summerfallow is largely responsible for increases in the area of cropped land, which expanded by 5.5 million hectares between 1981 and 2001.

> *Nationally, the amount of farmland under summerfallow decreased by more than half between 1981 and 2001, from 15% to 7%.*

In almost all areas of the country, the amount of land planted to cereals decreased as a proportion of annually cropped land (from 66% to 49%) between 1981 and 2001. Most of this 2.5 million-hectare contraction in the area of cereals reflects a shift to oilseeds, pulses and forages or other regional differences in crops. The use of soil-conserving tillage practices for crop production increased from 1991 (31%) to 2001 (60%), particularly in the three Prairie Provinces. The reasons for this are varied, but include increased awareness of the benefits of soil conservation and availability of large-scale equipment designed for soil conservation.

British Columbia: The total amount of farmland in British Columbia increased from 2.2 million hectares in 1981 to 2.6 million hectares in 2001, largely owing to an increase in the pasture and "other land" categories. Annually cropped land increased by approximately 57,000 hectares from 1981 to 2001, because of a gain of 30,000 hectares in total cultivated farmland and a decrease of about 27,000 hectares in summerfallow (from 3% in 1981 to 1% in 2001). The proportion of cropland devoted to cereal grains dropped from 30% in 1981 to 17% in 2001, while the proportion devoted to forage increased from 58% in 1981 to 70% in 2001. Cropped land used for other crops remained relatively constant over this period. The use of conventional tillage expressed as a proportion of cropped land fell from 83% in 1991 to 65% in 2001, when 21% of this land was under conservation tillage and 14% was no-till. Practices applied to summerfallow did not change appreciably over the three-census period, although chemical-only treatment of summerfallow increased slightly, from 3% to 6%.

Alberta: Alberta is the province with the second largest area of farmland in Canada, accounting for approximately 30% of the national total, or some 21 million hectares in 2001. Together, the amount of pasture and forage land increased by 2.2 million hectares between 1981 and 2001, indicating continued expansion of the livestock industry. The amount of cropped land expanded by almost 1.3 million hectares, mostly because the area of summerfallow decreased by 0.97 million hectares during this 20-year period, going from 12% of farmland in 1981 to 6% in 2001. Cropping patterns changed as producers diversified their production, reducing the amount of cropped land in cereals (from 71% in 1981 to 57% in 2001) and increasing the area of oilseeds by 0.47 million hectares and the area of pulses by 0.31 million hectares. The use of conventional tillage practices decreased dramatically from 73% of cropped land in 1991 to 37% in 2001, when 35% of this land was under conservation tillage and 27% was no-till. Treatment of summerfallow showed a similar trend, with soil conservation practices (tillage + chemical and chemical-only) used on 42% of summerfallow land in 1991 versus 62% in 2001.

Saskatchewan: Saskatchewan ranks first among the provinces in terms of area of farmland, with approximately 40% of the Canadian total or about 26 million hectares in 2001. Over the 20-year period under review, the amount of cropped land increased steadily by a total of 3.6 million hectares, with this trend occurring almost entirely because summerfallow shrank from 26% of total farmland in 1981 to 12% in 2001. The proportions of cultivated farmland, pasture and "other land" remained relatively constant over this 20-year period. Cropping patterns changed as producers diversified, reducing the amount of land in cereal grains from 85% of annually cropped land in 1981 to 58% in 2001;

Table 6-2: Cropping practices, 1981 to 2001

Share of Annually Cropped Land in Various Uses (in %)

Province	Cereal Grains					Oilseeds					Corn					Potatoes/Pulses[1]					Forages					Other Crops				
	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01
BC	30	22	22	22	17	4	8	7	5	4	2	2	2	2	2	1	1	1	1	1	58	62	63	64	70	5	5	6	8	7
AB	71	65	65	63	57	8	13	14	14	11	<1	<1	<1	<1	<1	<1	<1	1	1	3	20	21	20	21	27	0	0	0	1	1
SK	85	80	78	71	58	6	11	12	15	16	<1	<1	<1	<1	<1	<1	1	2	4	14	8	7	7	8	10	0	1	1	2	1
MB	67	64	62	60	52	15	19	18	19	21	2	1	1	1	1	1	2	3	2	3	13	14	15	16	20	1	1	1	2	2
ON	24	25	19	18	15	<1	1	1	1	<1	31	27	26	25	26	2	2	2	1	1	30	30	31	29	28	13	15	21	27	30
QC	20	20	20	16	17	<1	<1	<1	<1	<1	14	17	20	21	26	1	1	1	1	1	61	59	53	50	42	4	4	6	11	13
NB	20	21	21	22	21	na[2]	na	<1	<1	<1	1	1	1	1	2	17	15	17	16	16	56	56	53	50	52	7	7	8	11	9
NS	16	13	12	10	9	<1	<1	<1	<1	<1	4	4	3	4	5	1	1	2	2	2	65	64	64	58	58	13	17	20	27	26
PEI	46	45	41	37	36	na	<1	na	<1	na	2	1	1	1	1	16	17	20	26	25	33	34	33	32	33	3	3	4	4	5
NL	1	<1	3	2	3	<1	0	na	<1	0	1	1	0	0	2	8	5	4	5	3	74	80	78	70	75	16	14	14	23	16
Canada	**66**	**63**	**62**	**58**	**49**	**7**	**8**	**11**	**13**	**6**	**5**	**4**	**4**	**4**	**4**	**1**	**1**	**2**	**3**	**8**	**19**	**18**	**18**	**18**	**21**	**2**	**5**	**3**	**4**	**12**

[1] Percentages denote pulse crops for the 3 Prairie Provinces and Ontario, but potatoes for all other provinces. Canadian percentages denote potatoes + pulse crops.

[2] Not available due to data suppression.

and increasing the amount in oilseeds (from 6% to 16%) and pulses (from less than 1% to 14%). Together, the amount of pasture and forage land increased by 0.26 million ha, pointing to continued expansion of the livestock industry. The use of conventional tillage decreased from 64% of cropped land in 1991 to 32% in 2001, when 29% of this land was under conservation tillage and 39% was no-till. Treatment of summerfallow showed a similar trend, with soil-conserving practices (tillage + chemical and chemical-only) used on 43% of summerfallow in 1991 as compared to 52% in 2001.

Manitoba: Between 1981 and 2001, small changes occurred in the area of farmland in Manitoba, which remained relatively stable at approximately 7.6 million hectares. The proportions of cultivated farmland, pasture and "other land" also remained relatively constant over this 20-year period, accounting for about 65%, 26% and 9% of farmland respectively. The amount of farmland under summerfallow decreased by 0.34 million hectares, from 8% in 1981 to 3% in 2001, and annually cropped land exhibited an increase of similar magnitude. Cropping patterns changed as producers diversified, resulting in a drop in the area devoted to cereals (from 67% of cropland in 1981 to 52% in 2001) and an increase in oilseeds (from 15% of cropland in 1981 to 21% in 2001) and pulses (from 1% of cropland in 1981 to 3% in 2001). An increase in forage crops, from 13% to 20%, of cropped land, more than compensated for a decrease in pasture, pointing to continued commitment to the livestock industry. The use of conventional tillage practices on cropped land decreased from 66% in 1991 to 54% in 2001, when 33% of this land was under conservation tillage and 13% was no-till. Summerfallow treatments showed a similar trend, with soil-conserving practices (tillage + chemical and chemical-only) used on 50% of summerfallow in 2001, compared with 27% in 1991.

Ontario: The total amount of farmland, cultivated land and pasture all declined, whereas the amount of cropped land increased slightly, pointing to an intensification of cropping. Total farmland in Ontario decreased from 6.0 million hectares in 1981 to about 5.5 million hectares in 2001. Cultivation intensity increased, with cultivated land going from 61% of farmland to 67% and the proportion of pasture dropping from 24% of farmland to 15% over this 20-year period. The area of row crops as a proportion of total farmland decreased by about 2%, whereas the "other land" category remained fairly constant at about 17%. The amount of summerfallow was very small throughout this

Table 6-3: Tillage and summerfallow practices, 1991 to 2001

	Share of cropland area in various tillage practices (in %)									Share of summerfallow area in various regimes (in %)								
Province	**Conventional**			**Conservation**			**No-till**			**Tillage only**			**Till. and chemical**			**Chemical only**		
	91	**96**	**01**	**91**	**96**	**01**	**91**	**96**	**01**	**91**	**96**	**01**	**91**	**96**	**01**	**91**	**96**	**01**
BC	83	65	65	12	24	21	5	10	14	66	65	65	31	29	30	3	5	6
AB	73	57	37	24	33	35	3	10	27	58	51	39	37	38	38	5	11	24
SK	64	45	32	26	33	29	10	22	39	57	55	48	39	37	36	4	9	16
MB	66	63	54	29	28	33	5	9	13	73	61	50	24	34	38	3	6	12
ON	78	59	52	18	22	22	4	18	27	66	53	65	26	38	24	8	9	11
QC	85	80	77	12	16	19	3	4	5	48	43	56	28	25	18	24	32	26
NB	85	80	82	12	18	15	2	2	3	79	72	71	14	8	17	8	20	12
NS	88	77	71	8	20	20	4	3	8	72	62	69	19	26	19	9	13	12
PEI	91	82	76	8	16	22	1	2	2	35	55	44	23	32	17	42	13	39
NL	84	88	76	8	8	13	8	4	11	49	74	62	38	19	7	13	7	30
Canada	69	53	41	24	31	30	7	16	30	58	54	46	38	37	36	4	9	18

period, falling to less than 1% in 2001. The proportion of annually cropped land devoted to cereal grains dropped from 24% in 1981 to 15% in 2001. The proportion of cropped land used for other crops remained relatively constant over this period, with the exception of corn, which decreased from 31% in 1981 to 26% in 2001. The use of conventional tillage on cropped land decreased from 78% in 1991 to 52% in 2001, when 22% was under conservation tillage and 27% was no-till.

Quebec: As in Ontario, the changes in agricultural land point to an intensification of cropping. The total area of farmland decreased from 3.8 million hectares in 1981 to about 3.4 million hectares in 2001, whereas the amount of cropped land increased by about 0.1 million hectares. Cultivation intensity increased, with cultivated land going from making up 48% of farmland to 55% and the proportion of pasture declining from 21% to 11% of farmland over this 20-year period. The proportion of annually cropped land devoted to cereal grains dropped from 20% in 1981 to 17% in 2001, whereas the proportion of cropped land used for other crops remained relatively constant over this period, with the exception of corn, which increased from 14% to 26%, and forage, which decreased from 61% to 42%. The area planted to row crops increased from 8% of all farmland to16%, whereas the "other land" category remained fairly constant at about 34%. The use of conventional tillage declined from 85% of cropped land in 1991 to 77% in 2001, when 19% of this land was under conservation tillage and 5% was no-till. The amount of summerfallow was very small throughout this period, falling to less than 1% in 2001.

New Brunswick: Changes in agricultural land use in New Brunswick likewise indicate an intensification of cropping. The total amount of farmland in New Brunswick decreased from about 0.44 million hectares in 1981 to about 0.39 million hectares in 2001. Cultivation intensity increased, with cultivated land going from making up 31% of farmland to 39% and the proportion of pasture declining from 20% to 12% over this 20-year period. The proportion of farmland in row crops and in the "other land" category remained relatively constant at about 7% and 50% respectively. The amount of annually cropped land increased by slightly more than 20,000 hectares from 1981 to 2001. The proportion of cropland devoted to cereal grains, corn and potatoes remained fairly constant at approximately 21%, 2% and 16% respectively. Forages decreased from 56% of cropped land to 52% over the 20-year period. No clear trend is evident in the mix of tillage practices, as conventional tillage practices were used on approximately 82% of cropped land throughout the period. In 2001, approximately 15% of cropped land was under conservation tillage and 3% was no-till. The amount of summerfallow was very small throughout the period, falling to less than 1% in 2001.

Nova Scotia: The total amount of farmland and pasture in Nova Scotia decreased, whereas the amount of cropped land increased slightly, indicating an intensification of cropping. The total area of farmland in Nova Scotia decreased from about 0.47 million hectares in 1981 to about 0.41 million hectares in 2001. Cultivation intensity increased, with cultivated land going from 25% of farmland to 32% and the proportion of pasture decreasing from 20% to 14% over this 20-year period. The proportion of farmland in row crops and in the "other land" category remained relatively constant at approximately 2% and 57% respectively. The amount of cropped land expanded by slightly more than 15,000 hectares between 1981 and 2001. The proportion of cropland devoted to cereal grains decreased from 16% in 1981 to 9% in 2001, a decline of about 6,000 hectares. Corn and potatoes remained relatively constant over this period at approximately 4% and 2% respectively. The proportion of cropped land used for forage fluctuated around 60%. The use of conventional tillage on cropped land decreased from 88% in 1991 to 71% in 2001, when 20% was under conservation tillage and 8% was no-till. The amount of summerfallow was very small throughout the period, falling to less than 1% in 2001.

Prince Edward Island: The total amount of farmland and pasture in Prince Edward Island decreased, whereas the amount of cropped land increased slightly between 1981 and 2001. Farmland in Prince Edward Island decreased from about 0.28 million hectares in 1981 to about 0.26 million hectares in 2001. Cultivation intensity increased, with cultivated land going from 57% of farmland to 67% and the proportion of pasture declining from 18% to 10%. The proportion of farmland in row crops increased from 11% in 1981 to 18% in 2001. The proportion of land in the "other land" category fluctuated around 25%. The area of cropped land increased by slightly more than 17,000 hectares between 1981 and 2001. The proportion of cropland used for cereal grains decreased from 46% in 1981 to 36% in 2001, whereas the proportion in potatoes increased from 16% in 1981 to 25% in 2001. The proportion of cropped land in corn and forages remained relatively constant at 1% and 33% respectively. The use of conventional tillage decreased from 91% of cropped land in 1991 to 76% in 2001, when 22% was under conservation tillage and 2% was no-till. The amount of land under summerfallow was very small throughout this period, falling to less than 1% in 2001.

Newfoundland and Labrador: Between 1981 and 2001, the total amount of farmland in Newfoundland increased from about 33,000 hectares to about 40,000 hectares. Cultivated land increased slightly as a proportion of farmland, from 15% to 22%, whereas pasture shrank from 64% to 24% over the 20-year period. The proportion of farmland in row crops remained relatively stable at about 2%, and the proportion of "other land" fluctuated between about 50% and 60%. The amount of annually cropped land increased by slightly more than 4,000 hectares, with the proportion devoted to cereal grains increasing from 1% in 1981 to 3% in 2001. The proportion in potatoes decreased from 8% in 1981 to 3% in 2001, whereas forages fluctuated between about 75% and 80%. The use of conventional tillage on cropped land decreased from 84% in 1991 to 76% in 2001, when 13% was under conservation tillage and 11% was no-till.

REFERENCES

Agriculture and Agri-Food Canada (AAFC), 2004. *Census of Agriculture: Soil Landscapes of Canada* (SLC), v.3 and *Water Survey of Canada Sub-sub Drainage Area* (WSCSSDA), v.5, Re-allocation. Unpublished data for research purposes. AAFC, Ottawa (Ont.).

Dumanski, J., L.J.Gregorich, V. Kirkwood, M.A. Cann, J.L.B. Culley and D.R. Coote, 1994. *The Status of Land Management Practices on Agricultural Land in Canada*. Compiled from the 1991 Canada Census of Agriculture. Technical Bulletin 1994-3E. Agriculture and Agri-Food Canada, Ottawa (Ont.).

Statistics Canada, 1997. *Historical Overview of Canadian Agriculture*. Statistics Canada, Agriculture Division, Ottawa (Ont.).

7. Farm Environmental Management Practices

SUMMARY

Farm environmental management has important implications for the environmental sustainability of the agriculture sector and Canadian producers can implement environmentally beneficial management practices (BMPs) without compromising profitability. This chapter examines the level of adoption of beneficial management practices related to agricultural inputs such as mineral fertilizers, pesticides and manure, as well as water management. The analyses are based on a national farm environmental management survey conducted in 2001, but also make use of data obtained from other related information sources. For example, temporal trends in manure storage and application practices, identified through comparison with a 1995 survey, are also discussed.

In 2001, most Canadian farms used mineral fertilizers and one-half conducted soil testing, as recommended, at least once every three years. Producers tend to reduce fertilizer use when nutrients are supplied through manure spreading. With respect to fertilizer application methods, only 9% of farms used knifing-in or injection, the most environmentally beneficial approaches. However, application with seed, also a good practice because of the reduced potential for nutrient loss, was the prevalent method used throughout the grain growing regions of the Prairies, particularly in Saskatchewan (58%). About 62% of farms store manure from livestock in solid form. Liquid manure storage has gained increasing acceptance in the dairy sector, and liquid manure storage capacity is generally sufficient to ensure that good manure management practices can prevail. Manure application methods have changed little, but the optimal approach of injecting liquid manure is on the rise. Timing of manure incorporation is not always optimal, as many farms incorporate manure late or not at all, and only 15% use the most beneficial practice of promptly incorporating manure. However, as the prevalence of liquid manure systems increases, the practice of prompt incorporation is also expected to rise. Although pesticides are typically applied by a certified operator, the equipment is usually only calibrated at the start of the season; few producers re-calibrate before using a different pesticide. The timing of insecticide applications tends to be optimal, i.e. done when pest numbers exceed acceptable levels, especially in the Prairies. By contrast, the environmentally optimal signal for herbicide application—weeds exceeding acceptable levels—is not widely used. Overall, Canadian producers are maintaining vegetated riparian strips and keeping livestock away from water bodies, thereby helping to minimize adverse effects on surface waters.

AUTHORS:
R. Koroluk,
A. Piau, J. Grimard,
L. Bourque and
M. Korol

INFORMATION SOURCE:
Farm Environmental Management Survey

STATUS:
National coverage, 2001

THE ISSUE

From an environmental perspective, many farm management decisions are important because they represent a direct link between the primarily economic focus of agriculture and the potential environmental consequences of agricultural production. However, producers sometimes perceive changes in farming practices that are made solely for environmental reasons as being detrimental to farm profitability. Fortunately, this kind of trade-off does not always occur, as producers can adopt some beneficial management practices that allow them to maintain or improve productivity while protecting the environment. This chapter examines the extent to which the practices of Canadian farmers correspond to the notion of BMPs. The variables reported on here are not agri-environmental indicators per se. Rather, they are key pieces of information that provide valuable insight into the results and trends revealed by the indicators covered in this report. More specifically, the present chapter focuses on the level of adoption of a subset of key BMPs related to mineral fertilizers, manure, pesticides and water management.

Mineral fertilizers: An adequate supply of nutrients, especially nitrogen, *phosphorus* and potassium, is essential to good plant growth. Many farmers seek to maximize the productivity and economic returns of their crops by applying mineral fertilizers. When correctly applied in the right amounts, these inputs help produce a robust crop that will yield a good harvest. An undersupply can lead to depletion of the nutrients in the soil and in turn spell economic losses for farmers. The total economic costs of adding inputs—purchase, transportation and application—is a significant part of the farm budget. The environmental costs of applying nutrients can also be high. Excess nutrients can be lost from farmland through *leaching*, evaporation or run-off, potentially creating environmental problems such as surface and groundwater pollution, deposition of *ammonia* and acid rain, and emissions of nitrous oxide (a greenhouse gas). By applying beneficial management practices to optimize fertilizer use, farmers can improve yields while keeping costs down and protecting the environment.

In March 2002, Statistics Canada, in partnership with Agriculture and Agri-Food Canada, conducted a survey on environmentally-related farm management practices.

Manure: Growing livestock populations and greater concentrations of animals in certain geographic areas have led to heightened concerns about methods of manure storage and application. This is perhaps the greatest environmental challenge that livestock producers face, a challenge that is likely to increase as livestock numbers grow and farming operations become larger and more intensive. As an agricultural input, manure can be an inexpensive source of crop nutrients, offsetting the cost and the potential environmental risks of mineral fertilizers. However, excessive or incorrect application can give rise to environmental problems such as *run-off* into surface waters and leaching into groundwater. This is particularly problematic in local areas with limited farmland, high livestock concentrations and encroaching urban populations.

Pesticides: Chemical pesticides are used to limit damage to crops and mitigate economic losses caused by crop pests. However, they, too, can contribute to environmental degradation. Although the newer pesticide products are generally safer and pose fewer environmental risks, there is still concern about the impacts of pesticides on non-target species and on water quality. Poor choice of pesticides and inappropriate timing and application may lessen soil and water quality because of the presence of pesticide residues, reduced air quality from spray drift and vapour from volatilized spray materials. Furthermore, there may be negative impacts on biodiversity because of the effects on non-target species and interference with normal predator–prey relationships.

Water: The protection of water quality is a top environmental priority for all Canadians, as evidenced by recent health concerns related to domestic water supplies. Furthermore, agricultural producers require reliable supplies of high-quality water for irrigation and livestock watering. Changes in production practices and land use in many areas in recent decades have had negative impacts on water quality, mainly through increased presence of sediment, pathogens, nutrients and pesticides in nearby water bodies. In addition to effective nutrient and pesticide management, producers can apply some beneficial management practices to minimize the risk of water contamination, such as protecting *riparian areas* and controlling access to waterways by grazing animals.

■ THE SURVEY

In March 2002, Statistics Canada, in partnership with Agriculture and Agri-Food Canada, conducted a survey on environmentally-related farm management practices—the 2001 Farm Environmental Management Survey or FEMS (Statistics Canada 2002). A questionnaire with

57 questions on various aspects of the management of manure, fertilizers, pesticides, water and land, as well as on environmental farm planning, was sent to 22,000 farms across Canada (excluding the Yukon, Northwest Territories and Nunavut) with sales of greater than $10,000. The survey was designed to provide results complementing the information compiled in the 2001 Census of Agriculture (Statistics Canada 2001). It was well received and achieved an overall response rate of more than 76%.

The information presented in this chapter has been compiled from a subset of 15 variables analysed in FEMS. The comprehensive results of FEMS are available from Statistics Canada. Additionally, the manure storage and application results of FEMS are compared with those from a similar survey—the 1995 Farm Inputs Management Survey or FIMS (Statistics Canada 1995). This was done to provide a time-based comparison of the level of adoption of specific beneficial management practices.

LIMITATIONS

Farm management practices and their environmental impacts vary regionally since agricultural production, soil quality, landscape, weather and other aspects also vary from one region to another. This regional variation sometimes makes it difficult to interpret survey results in a consistent way. For example, practices that entail higher risks in one region may well be acceptable in other regions. Readers are advised to use caution when interpreting the FEMS results presented in this chapter. Though interesting and relevant, these results are insufficient in themselves to assess environmental risks. The FEMS data are meant to provide an overall picture of the level of adoption of various farming practices that may affect the environment. To have a full appreciation of the implementation of environmental management practices and of their impacts (positive or negative) on *agroecosystems*, additional information and more comprehensive analysis is required. Such information is provided by the agri-environmental indicators presented in this report. Finally, for manure management practices, differences in survey design between FIMS and FEMS may have affected comparisons of the 1995 and 2001 results, although attempts have been made to account for this.

RESULTS AND INTERPRETATION

Mineral fertilizer: Results are presented in Table 7-1. The proportion of farms that use mineral fertilizer on crops is provided for reference. In 2001, 75% of farms in Canada used fertilizer, with the highest proportion in Prince Edward Island (85%) and Ontario (81%). British Columbia had the lowest proportion of farms using fertilizer (62%), followed by Alberta and New Brunswick (69% each).

1) ***Method of fertilizer application:*** This aspect is expressed as the proportion of farms that use the following methods of mineral fertilizer placement (ranked from most to least environmentally desirable): injected into soil (liquid fertilizers and anhydrous ammonia) or banded (dry fertilizer), applied with seed, broadcast or other. Injection reduces odours and volatilization of nitrogen and enhances crop uptake, whereas banding increases crop uptake by placing fertilizer near the root. Broadcasting accounted for about one-third of all mineral fertilizer application in Canada, as did application with seed. Broadcasting was the most popular method in all provinces except in the Prairies, where applying fertilizer with seed was more commonplace. The most environmentally friendly option of knifing-in or injecting fertilizer into the ground accounted for only 9% of all commercial fertilizer application methods in Canada. This practice was most prevalent in the Prairies. Banding accounted for a little over 17% of all methods.

2) ***Use and frequency of soil nutrient testing:*** This is expressed as the proportion of farms using mineral fertilizer that conduct soil tests at specified intervals: every year; every two to three years; every four to five years; at intervals of over five years; and soil not tested. The greater the frequency of soil testing, the greater the likelihood that nutrient application rates will be matched to crop requirements. Soil testing at least once every three years is desirable. FEMS results

Table 7-1: Selected aspects of mineral fertilizer management in Canada, 2001

	BC	AB	SK	MB	ON	QC	NB	NS	PEI	NL	Canada
Application of mineral fertilizer	**Share of farms growing crops (in %)**										
Farms using mineral fertilizers	**62**	**69**	**75**	**78**	**81**	**71**	**69**	**76**	**85**	**71**	**75**
Method of fertilizer application	**Share of farms using mineral fertilizers (in %)**										
Injected or knifed-in	5	10	11	11	7	6	X	2	X	X	9
Post-plant, top/side dressing	7	1	1	2	4	5	X	7	4	X	3
Applied with seed	9	41	58	40	22	27	X	12	31	X	36
Banding	11	18	21	20	15	15	15	10	22	16	17
Broadcasting	56	28	9	26	49	45	51	65	41	56	33
Other	12	2	1	1	3	1	X	5	X	X	2
Frequency of soil nutrient testing	**Share of farms using mineral fertilizers (in %)**										
Every year	16	26	17	26	14	20	23	11	29	23	20
Every 2 to 3 years	23	23	24	27	38	39	22	23	30	27	30
Every 4 to 5 years	10	9	10	9	15	23	16	17	15	15	13
Every 5 years or more	19	12	13	13	13	9	21	21	X	X	13
Not tested	33	30	35	25	20	8	19	30	X	X	25
Reduction of fertilizer to offset manure	**Share of farms using mineral fertilizers (in %)**										
Yes	32	39	21	37	55	72	55	56	72	59	43
No	16	15	17	15	8	5	22	13	X	X	13
Not applicable	52	46	61	49	37	23	24	32	X	X	44
Nutrient management plan (NMP)	**Share of farms using mineral fertilizers (in %)**										
Farms that have a NMP	11	11	6	13	12	47	14	5	9	10	15

X: Data suppressed to maintain confidentiality

Source: Statistics Canada, 2001 Farm Environmental Management Survey

indicate that soil testing is a popular method of deciding on the amount and type of commercial fertilizer to apply. About three-quarters of farms in Canada test their soils to determine the level of nutrient carry-over and almost 50% of these farms do so at least every three years. Most farmers test soils every two or three years, while less than 20% carried out soil testing on an annual basis. Among the provinces, farmers in Quebec and Prince Edward Island tested their soil more frequently, while in Nova Scotia and, to a lesser extent, British Columbia, testing tended to be done less frequently. About 40% of farmers in Central Canada tested their soil every two to three years.

3) ***Reduction in fertilizer use to offset nutrients in manure:*** This is expressed as the proportion of farms using mineral fertilizers that reduce the amount of fertilizer when using manure (yes), versus those that don't (no), or for which this practice is not applicable (e.g. don't use manure on their land). Accounting for manure inputs reduces the risk of oversupplying nutrients and subsequent losses to the environment. Approximately 43% of Canadian farmers reduced their fertilizer application to land to which manure had been applied, while 13% did not. This situation is not applicable to the remaining 44% of farms applying fertilizers. The proportion of farms that follow this beneficial management practice is somewhat higher in Eastern Canada and lower in the western provinces.

4) ***Nutrient management plans (NMP):*** This reflects the proportion of farms that have developed a nutrient management plan—a formal written plan that is prepared by a trained person or specialist and that considers issues such as application method and timing, carry-over of nutrients and distance from water bodies. These plans may be developed out of a desire to increase the efficiency of nutrient use and to minimize risks to the environment, or in accordance with provincial government regulations. According to FEMS, 47% of farms in Quebec have a NMP, a significantly higher percentage than in other Canadian provinces.

Manure: Results are presented in Table 7-2 (manure storage) and Table 7-3 (manure application). Survey results showed that, in 2001, animal manure was stored on about 76% of Canadian farms with livestock. About 62% of these farms stored manure in solid form, 7% in liquid form and 7% in both solid and liquid form. Comparisons between 1995 and 2001 relating to five variables are discussed below. Generally, survey results suggest that significant recent investments in the livestock sector have included investments in new state-of-the-art liquid systems.

5) ***Storage methods for solid and liquid manure:*** This is expressed as the percentage of animals (dairy cattle, beef cattle and hogs) for which various storage systems are used. For solid manure, storage methods include the following: covered storage pad (optimal), open pad with run-off containment, open pad without containment, manure pack, covered open pile, uncovered open pile (riskiest) and other methods. For liquid manure, storage methods consist of a sealed covered tank (optimal), tank below slatted floor, open tank, lined lagoon, unlined lagoon (riskiest) and other methods. Liquid manure systems are sometimes considered environmentally safer than solid manure systems because of the greater level of manure containment they provide and because they are usually designed by engineers and companies that specialize in their construction. Nonetheless, liquid systems often require more labour and greater management intervention for effective operation. Furthermore, solid systems are not necessarily environmentally detrimental given favourable factors like production system or agronomic conditions.

In dairy production, liquid manure storage is increasingly being used, as evidenced by the expanding proportion of dairy cattle managed with liquid manure systems between 1995 and 2001. Increases in the use of these systems are observed in most regions, especially in Manitoba and Saskatchewan. In addition, the type of liquid system in use has improved as farmers have moved from low-containment solid systems, such as open piles without roofs, to high-containment tank-based liquid systems. Although more beef farms are using liquid systems, they still represent a very small segment of the beef sector. More importantly, beef producers have shifted from lower containment solid systems (open piles without a roof/open pad without containment) to higher containment systems (open piles with a roof/open pad with containment). In 1995, hog producers mainly used liquid manure storage systems in all regions except Atlantic Canada. By 2001, however, Atlantic region hog production had shifted to liquid systems to the same extent as the rest of the country.

6) ***Manure application method:*** This is expressed as the percentage of crop area receiving manure through various application methods. For liquid manure, injection directly into the soil is considered the best practice. Surface application and irrigation-system application typically produce more odours and are often more susceptible to nutrient run-off and ammonia nitrogen losses. Methods of manure application to land did not change significantly between 1995 and 2000. Solid manure application by spreader declined in all provinces except British Columbia, a trend likely related to the larger number of liquid manure storage systems across Canada. Application through irrigation systems, never a prevalent practice and noteworthy only in Ontario and British Columbia, shows a downtrend across the country. The practice of applying liquid manure to the surface increased in each of the eastern provinces but declined in three

Table 7-2: Selected aspects of manure storage practices in Canada, 1995, 2001

SOLID MANURE

Share of animals treated with each method (in %)

	BC		AB		SK		MB		ON		QC		Atlantic		Canada	
	95	**01**	**95**	**01**	**95**	**01**	**95**	**01**	**95**	**01**	**95**	**01**	**95**	**01**	**95**	**01**
Dairy cattle																
Open pile – without roof	21	7	20	31	56	39	36	30	21	19	53	20	57	30	35	21
Open pile – with roof	0	1	3	4	0	1	0	0	0	1	1	2	1	1	0	2
Manure pack	0	6	17	33	40	30	40	33	4	10	0	1	2	6	4	9
Open pad, no containment	2	2	0	1	0	0	0	0	20	12	7	3	0	6	10	6
Open pad with containment	2	7	0	1	0	3	14	2	13	14	13	16	9	8	11	12
Covered storage pad	2	9	0	0	0	0	0	0	0	2	1	5	3	7	1	3
Other solid storage	2	2	14	2	0	2	4	5	3	4	1	7	10	4	3	5
Total solid storage	**30**	**34**	**54**	**73**	**97**	**75**	**94**	**71**	**60**	**61**	**75**	**54**	**82**	**60**	**65**	**57**
Beef cattle																
Open pile – without roof	49	58	46	50	52	49	45	57	40	32	71	45	62	48	48	47
Open pile – with roof	1	1	2	1	1	2	6	2	5	3	1	5	0	3	2	2
Manure pack	47	28	52	35	46	36	46	32	11	23	7	12	20	22	43	31
Open pad, no containment	2	1	0	3	0	2	1	0	27	15	8	2	4	5	4	5
Open pad with containment	0	5	0	2	1	1	1	0	9	10	8	9	4	9	2	4
Covered storage pad	0	3	0	0	0	0	0	0	3	1	1	7	2	1	0	1
Other solid storage	0	1	0	4	0	9	1	9	0	2	3	6	1	1	0	5
Total solid storage	**100**	**97**	**100**	**95**	**99**	**100**	**100**	**100**	**94**	**84**	**98**	**86**	**93**	**89**	**99**	**94**
Hogs																
Open pile – without roof	3	1	6	7	10	4	1	4	4	3	0	3	8	9	4	4
Open pile – with roof	0	1	0	5	1	0	0	2	0	0	0	0	0	0	0	1
Manure pack	1	0	1	3	5	3	1	2	0	7	0	1	0	3	1	4
Open pad, no containment	0	0	0	1	0	0	0	1	8	2	0	0	0	4	2	1
Open pad with containment	0	0	0	0	0	2	0	0	3	3	0	1	0	1	1	1
Covered storage pad	0	0	0	0	0	6	1	0	0	0	0	1	16	0	1	1
Other solid storage	0	4	1	9	0	2	1	5	0	1	0	0	28	1	1	3
Total solid storage	**4**	**5**	**9**	**24**	**15**	**18**	**4**	**14**	**16**	**16**	**0**	**5**	**52**	**17**	**9**	**14**

LIQUID MANURE

Share of animals treated with each method (in %)

	BC		AB		SK		MB		ON		QC		Atlantic		Canada	
	95	**01**	**95**	**01**	**95**	**01**	**95**	**01**	**95**	**01**	**95**	**01**	**95**	**01**	**95**	**01**
Dairy cattle																
Unlined lagoon	37	17	9	16	1	13	0	9	10	14	14	8	5	11	13	12
Lined lagoon	13	18	23	4	0	3	0	7	4	3	0	2	5	3	5	4
Open tank	13	14	10	1	0	3	1	3	11	13	11	29	6	9	10	17
Tank below slatted floor	0	6	4	5	3	1	0	4	10	7	0	1	2	10	4	4
Sealed covered tank	8	9	0	1	0	3	5	3	5	2	0	2	1	5	3	3
Other liquid storage	0	2	0	1	0	1	0	3	0	1	0	5	0	2	0	3
Total liquid storage	**70**	**66**	**46**	**27**	**3**	**25**	**6**	**29**	**40**	**39**	**25**	**46**	**19**	**40**	**35**	**43**
Beef cattle																
Unlined lagoon	0	0	0	5	1	0	0	0	0	2	1	2	7	4	0	3
Lined lagoon	0	3	0	0	0	0	0	0	1	0	0	1	0	0	0	0
Open tank	0	0	0	0	0	0	0	0	4	9	1	8	0	0	1	2
Tank below slatted floor	0	0	0	0	0	0	0	0	0	4	0	1	0	4	0	1
Sealed covered tank	0	0	0	0	0	0	0	0	1	0	0	1	0	4	0	0
Other liquid storage	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Total liquid storage	**0**	**3**	**0**	**5**	**1**	**1**	**0**	**0**	**6**	**16**	**2**	**14**	**7**	**11**	**1**	**6**
Hogs																
Unlined lagoon	48	9	21	22	28	18	38	27	10	4	50	5	13	13	30	12
Lined lagoon	0	32	15	33	46	17	1	22	3	2	0	0	13	1	9	12
Open tank	0	5	6	2	0	0	3	7	24	32	44	74	12	31	18	30
Tank below slatted floor	0	41	47	14	11	45	9	18	18	38	0	1	9	17	17	21
Sealed covered tank	48	9	2	3	0	2	46	6	29	8	3	4	0	21	17	5
Other liquid storage	0	0	2	1	1	1	0	8	0	1	3	12	0	0	1	5
Total liquid storage	**96**	**95**	**91**	**76**	**85**	**82**	**96**	**88**	**85**	**84**	**100**	**95**	**48**	**83**	**91**	**86**

X: Data suppressed to maintain confidentiality. Source: Statistics Canada, 2001 Farm Environmental Management Survey
Source: Statistics Canada, 1995 Farm Inputs Management Survey

Table 7-3: Selected aspects of manure application practices in Canada, 1995, 2001

Share of crop area receiving manure by each method (in %)

	BC		AB		SK		MB		ON		QC		NB		NS		PEI		NL		Canada	
	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01
Manure application method																						
Solid manure spreader	60	65	82	81	89	85	70	66	73	66	62	53	79	69	73	68	85	79	62	57	**73**	**67**
Irrigation system application	3	4	1	0	0	0	3	1	5	4	3	1	1	1	1	0	0	0	1	1	**3**	**2**
Surface liquid manure application	34	30	15	15	8	6	24	17	22	28	33	42	21	30	26	31	15	21	37	42	**23**	**26**
Injected liquid manure	3	1	3	3	3	9	3	16	1	3	2	4	0	1	1	1	0	0	0	0	**2**	**5**

Share of manure produced (in %), 2001*

	BC	AB	SK	MB	ON	QC	NB	NS	PEI	NL	Canada
Timing of manure incorporation into soil											
Injected or incorporated the day of application	16	18	14	21	20	18	16	X	14	X	**18**
Manure incorporated within one week of application	29	34	30	34	43	37	41	X	33	X	**35**
Manure left on surface or incorporated after more than 7 days	55	48	56	46	37	45	44	X	54	X	**47**

*: Data is available for 2001 only

X: Data suppressed to maintain confidentiality

Share of farms that store liquid manure (all livestock combined) (in %)

	BC		AB		SK		MB		ON		QC		NB		NS		PEI		NL		Canada	
	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01
Liquid manure storage capacity																						
100 days or fewer	21	8	41	26	36	40	71	34	5	5	2	X	0	X	16	0	X	X	0	0	**17**	**8**
101 to 151 days	13	38	13	9	13	X	6	14	12	5	4	X	50	X	16	17	0	X	0	X	**10**	**6**
151 to 200 days	44	37	16	9	0	10	X	8	32	23	10	7	0	21	31	28	74	30	X	70	**20**	**15**
201 to 250 days	7	6	3	9	0	X	X	2	18	18	18	20	50	21	22	30	X	25	X	X	**13**	**16**
More than 250 days	15	11	28	47	51	39	23	42	33	50	67	71	0	X	16	25	0	X	X	X	**40**	**55**

X: Data suppressed to maintain confidentiality

Share of manure applied each season (in %)

	BC		AB		SK		MB		ON		QC		NB		NS		PEI		NL		Canada	
	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01	95	01
Timing of manure application																						
Winter	9	5	5	3	5	2	7	2	6	4	0	0	1	0	2	X	2	X	2	0	**4**	**2**
Spring	46	53	27	30	20	28	19	20	41	40	27	50	40	53	45	42	61	50	59	54	**30**	**35**
Summer	11	19	14	21	26	25	23	23	19	23	23	X	23	0	13	27	8	X	16	13	**20**	**27**
Autumn	35	23	54	46	49	45	52	56	35	32	50	0	36	47	41	29	29	35	22	33	**46**	**36**

X: Data suppressed to maintain confidentiality

Source: Statistics Canada, 2001 Farm Environmental Management Survey

Source: Statistics Canada, 1995 Farm Inputs Management Survey of the four western provinces (though Alberta essentially shows no change). Injection of liquid manure has increased in all provinces (except British Columbia), particularly in Manitoba and Saskatchewan, the two provinces showing the largest shifts from solid manure systems to liquid manure systems in their dairy sectors.

7) ***Timing of manure incorporation into soil:*** This is expressed as the percentage of manure incorporated into the soil at various time periods following application. Immediate injection or incorporation as soon as possible after spreading are considered the most environmentally beneficial practices, as they reduce odour problems and risks associated with run-off and nutrient losses. On average, only 15% of farms inject liquid manure or incorporate solid manure the same day as it is applied to land. The farms that do this tend to be larger than average, collectively accounting for 18% of the manure produced. Incorporation within a week of application, the second best practice, is done by 32% of farms comprising 35% of manure production. The least environmentally favourable practice of late or no incorporation characterizes more than half (52%) of all farms, representing slightly less than half (47%) of the manure produced. The patterns of manure incorporation do not differ significantly among the provinces, although broadly speaking, New Brunswick, Quebec and Ontario tend to incorporate surface-applied manure more promptly than the other provinces. It should be noted that information on this variable is available only for 2001, so comparisons cannot be made with 1995.

In general, liquid manure storage capacity increased between 1995 and 2001.

8) ***Liquid manure storage capacity:*** This is expressed as the percentage of all farms that use liquid manure storage systems of different capacities. Ideally, this capacity should be sufficient to provide flexibility in the timing of manure application, allowing this to be done when both environmentally and economically optimal. The optimum time frame for application varies by region, but a minimum capacity of 200 days is considered a good benchmark. In general, liquid manure storage capacity increased between 1995 and 2001 on all farms with these systems. The number of lower capacity systems, holding fewer than 200 days of production, has declined and have been replaced by higher capacity storage systems. Over half (55%) of farms with liquid systems in 2001 could store more than 250 days of manure production compared to 40% in 1995. In fact, 10% of farms could store more than 400 days of manure production.

9) ***Timing of manure application:*** This is expressed as the percentage of manure applied during each season. Application in the summer after planting makes nutrients immediately available to growing crops, reducing the risk of losses to the environment. Application in spring, prior to planting, and in fall, after harvest, is more prone to some nutrient losses. Winter application is generally not considered appropriate, although it can safely be practiced in some areas with very short winters, such as southern Ontario and Vancouver Island. Elsewhere though, losses to the environment are likely to be high because of the inability of frozen ground to absorb manure nutrients. Although most manure in Canada is applied in autumn and spring respectively, application patterns differ from region to region because of differences in the type of livestock and crops produced. Farmers in British Columbia, Ontario and the Atlantic Region apply the bulk of their manure production in the spring. Conversely, farmers in the Prairie Provinces apply the bulk of their manure production in the autumn.

Pesticides: Results are presented in Table 7-4. The proportion of farms growing crops that use pesticides (herbicides, insecticides and fungicides) is provided for reference. In 2001, 73% of farms in Canada used at least one pesticide. This represents a slight drop of 4% from 1995 (not shown in table). The largest percentage

Table 7-4: Selected aspects of pesticide (herbicides, insecticides, fungicides) management in Canada, 2001

	BC	AB	SK	MB	ON	QC	NB	NS	PEI	NL	Canada
Application of pesticides											
Share of farms growing crops (in %)											
Farms using pesticides	48	65	83	77	79	68	54	48	80	56	**73**
Certified pesticide applicator											
Share of farms using pesticides (in %)											
Pesticides applied by a formally certified person	65	48	36	54	93	62	93	X	95	X	**61**
Sprayer calibration frequency											
Share of farms using pesticides (in %)											
Upon breakage / major component replacement	5	4	4	3	2	9	4	X	6	X	**4**
Before beginning of each crop season	39	46	54	54	45	49	52	54	60	41	**49**
Between applications of different pesticides	15	13	18	13	12	8	11	13	8	37	**14**
Other	9	5	5	7	6	12	6	X	5	X	**6**
Never	4	6	6	4	2	3	4	X	8	X	**4**
Not applicable	28	26	14	20	33	20	22	26	14	19	**23**
Timing of herbicide application											
Share of farms using herbicides (in %)											
Based on calendar dates	11	3	3	1	10	6	8	19	6	24	**6**
At the first sign of weeds	29	16	18	16	17	28	17	14	15	48	**19**
Based on crop growth stage	29	56	52	48	50	41	48	51	61	20	**50**
Based on regional monitoring of weeds	13	14	15	24	15	12	15	X	10	X	**15**
When weeds exceed acceptable levels	17	10	11	10	9	14	13	X	8	X	**11**
Timing of insecticide application											
Share of farms using insecticides (in %)											
Based on calendar dates	8	2	2	3	11	6	4	7	X	X	**5**
At the first sign of pests	33	26	27	28	26	35	28	42	35	71	**28**
Based on crop growth stage	13	8	5	11	19	11	15	X	16	X	**11**
Based on regional monitoring of pests	14	13	12	16	15	24	17	X	X	X	**15**
When pest numbers exceed acceptable levels	32	52	53	43	29	24	37	X	30	X	**41**
Alternative methods of pest control											
Share of farms growing crops, more than one option per farm is possible (in %)											
Tolerant or resistent plant	2	5	7	7	6	4	2	6	3	X	**6**
Intercropping	2	3	2	3	2	2	1	3	1	8	**2**
Green manure	3	2	2	2	4	9	4	4	5	8	**3**
Cover cropping	6	6	3	4	8	4	6	8	6	6	**5**
Fall seeding	3	2	2	6	3	1	4	6	4	X	**3**
Tillage	16	37	47	44	23	27	20	16	24	18	**32**
Mechanical weeding with rotary hoe	4	2	1	1	5	7	4	3	3	7	**3**
Mechanical weeding with cultivator	9	13	20	14	14	19	11	5	15	13	**15**
Hand weeding	18	6	3	3	12	6	7	18	5	21	**8**
Predators	4	1	0	0	1	1	X	4	1	0	**1**
Parasites	2	X	0	0	1	X	0	1	X	X	**0**
Parsitoids	0	0	0	0	0	X	0	X	X	0	**0**
Pheromones	4	0	X	0	0	0	X	2	X	0	**0**
Pathogens	0	X	X	X	0	0	0	X	0	0	**0**
Bacillus thuringiensis (Bt)	3	0	0	1	4	4	X	2	X	0	**2**
Ground cover	5	3	2	2	3	1	2	5	2	X	**3**
Floating covers	1	0	X	0	0	0	2	1	0	X	**0**
Mulching	8	2	1	2	3	2	2	5	3	6	**2**
Pit traps	1	0	X	X	0	0	X	X	0	X	**0**
Other methods	10	18	11	11	10	14	35	7	25	X	**13**

X: Data suppressed to maintain confidentiality

Source: Statistics Canada, 2001 Farm Environmental Management Survey of farmers who applied pesticides are found in Saskatchewan (83%), followed by Prince Edward Island (80%) and Ontario (79%). British Columbia and Nova Scotia have the smallest proportion of farmers using pesticides (48%).

10) ***Certified pesticide applicator:*** This is expressed as the proportion of farms using pesticides where pesticide application is handled by someone with certified training to do so. Given the nature of pesticides and the importance of proper handling and application, producers were asked whether pesticide application on their farm is done by a formally certified person. Nationally, 61% of farmers responded affirmatively. In Ontario, Prince Edward Island and New Brunswick, the percentage of certified applicators was well over 90%.

11) ***Sprayer calibration frequency:*** This is expressed as the percentage of farms that apply pesticides using equipment that has been calibrated at specified intervals: between applications of different herbicides (optimal); at the start of the crop season; when the sprayer breaks down or major parts are replaced; other and not applicable (pesticides not applied with a sprayer). Calibration before applying a different pesticide helps ensure that application is at the correct rate. Almost half of the farmers in Canada only calibrate their sprayers at the start of each season. Only 14% of Canadian farmers calibrate their sprayer between applications of different pesticides (the best practice), indicating that there is room for improvement.

12) ***Timing of herbicide and insecticide application:*** This is expressed as the proportion of farms using herbicides where treatment is timed according to one of the following: when weeds exceed acceptable level (e.g. economic injury threshold), which is the optimal practice; regional monitoring of weeds; crop growth stage; first sign of weeds; or calendar dates (riskiest practice). Applying pesticides only when weed pressures approach or exceed economic levels reduces quantities used and associated costs and environmental risks.

Half (50%) of the farms in Canada apply herbicides based on the growth stage of their crop. All provinces reported similar percentages, except Newfoundland and Labrador (NL) and British Columbia, which had much lower values. The second most frequent trigger for herbicide application was the first sign of weeds (19%), followed by regional monitoring of pests (15%). The former method was popular in Newfoundland and Labrador and British Columbia. The riskiest practice—applying herbicides based on calendar date—was the least used method in all provinces except Ontario (only 10%) and Newfoundland and Labrador (24%). This approach was fairly prevalent in Nova Scotia (19%). With respect to insecticide use, 41% of farmers applied insecticides when they felt that the level of pests exceeded acceptable levels (optimal practice). While considerable variation was observed across Canada, this method was especially popular in the Prairies (between 43% and 53%). Another 28% of Canadian farmers applied insecticides at the first sign of pests (Newfoundland and Labrador had the highest proportion, at 71%).

13) ***Alternative methods of pest control:*** This is expressed as the proportion of farms using various non-chemical pest control alternatives. While most of these methods have been commonplace for many years (i.e. tillage), some are more recent innovations (e.g. Bacillus thuringiensis). Although there is no single most optimal practice, these alternative approaches are generally indicative of efforts to minimize pesticide use whenever possible. Tillage is the most common method used across Canada to control weeds. Mechanical weeding with cultivators and hand weeding are also used frequently. Some of the pest control practices can be described as biological methods, since they involve utilizing biological agents such as predators and parasites. These biological methods represent a relatively small percentage of all alternative methods of pest control, with British Columbia, Nova Scotia, Ontario and Quebec being somewhat above the national average.

Water: Some beneficial farm management practices can be adopted to minimize the environmental threats to surface water bodies from farming activities. In addition to farm input management, FEMS sheds light on the level of adoption of some water management practices, three of which are discussed below (Table 7-5).

14) ***Vegetation of areas adjacent to natural sources of water:*** This is expressed as the proportion of farms with area adjacent to surface water bodies that are keeping these areas vegetated. The presence of vegetative cover on areas adjacent to natural water bodies helps prevent the degradation of banks and captures farmland run-off containing soil particles, nutrients and pesticides. The survey asked whether farmers used this practice, but it did not collect information on the extent to which they did so (e.g. all potential areas or only a portion of them). In 2001, 76% of Canadian farms maintained vegetative cover on at least a portion of their land adjacent to natural water bodies. The proportion is comparable for all the provinces, though slightly higher in Western Canada and in Ontario.

Table 7-5: Selected aspects of farm management practices for water protection in Canada, 2001

	BC	AB	SK	MB	ON	QC	Atlantic	Canada
Vegetation of areas adjacent to natural surface water	Share of farms with areas adjacent to natural surface water (in %)							
Yes*	77	76	79	79	78	70	73	**76**
No	23	24	21	21	22	30	27	**24**
Prevent direct access of grazing livestock to surface water bodies	Share of farms with grazing livestock (in %)							
Yes	63	52	41	54	74	60	61	**57**
No	37	48	59	46	26	40	39	**43**
Feed grazing livestock more than 100 metres away from surface water bodies during winter	Share of farms with grazing livestock (in %)							
Yes	90	93	89	91	91	90	88	**91**
No	10	7	11	9	9	10	12	**9**

* : At least a portion of the areas adjacent to natural surface water on these farms is vegetated
X: Data suppressed to maintain confidentiality
Source: Statistics Canada, 2001 Farm Environmental Management Survey

15) ***Prevention of livestock access to surface water bodies:*** This is expressed as the proportion of farms with grazing livestock that prevent these animals from having direct access to surface water bodies. Grazing animals can deposit manure directly in the water, increasing the load of nutrients and the risk of pathogen contamination. They can also alter riparian areas, causing increased erosion, compaction and sedimentation. Nationally, in 2001, 57% of farms with grazing livestock did not allow livestock access to surface water bodies, with the highest proportions observed for eastern provinces (especially Ontario) and British Columbia (higher than 60% in all cases).

16) ***Feeding of grazing livestock away from surface water bodies during winter months:*** This is expressed as the proportion of farms with grazing livestock that do not feed their animals within 100 metres of surface water bodies during the winter. The feeding of grazing livestock in concentrated areas near surface water bodies could have negative impacts on water quality through run-off losses of nutrients and pathogens from feeding areas. Feeding livestock in areas away from surface water bodies is an effective way to reduce this type of risk. In 2001, this BMP was adopted by almost all farms with grazing livestock, as 91% of Canadian farms with grazing livestock reported that they did not feed animals within 100 metres of surface water bodies during the winter. This very high percentage was very consistent among the provinces.

RESPONSE OPTIONS

The findings presented in this chapter show that good practices related to mineral fertilizers, manure, pesticides and water management are being applied on farms across Canada. Although manure management practices have improved somewhat, the findings suggest that there is still considerable room for improvement in this area. The overall trend in Canadian agriculture is toward increased specialization and intensification of production, along with the use of more sophisticated processes and technologies. As agriculture continues to move to larger and more intensive operations, sound farm management practices will be critical for environmental protection, especially in areas of intensive crop or livestock production and in areas where landscape and climatic conditions are susceptible to increased environmental risks. In most cases, reducing the environmental risks associated with input management goes hand in hand with farm profitability.

REFERENCES

Statistics Canada, 2001. *Census of Agriculture.* Statistics Canada, Agricultural Division, Ottawa (Ont.). www.statcan.ca/english/agcensus2001/index.htm

Statistics Canada, 2002. *Farm Environmental Management in Canada.* Statistics Canada, Agriculture Division, Ottawa (Ont.). www.statcan.ca:8096/bsolc/english/bsolc?catno=21-021-M

Statistics Canada, 1995. *Farm Inputs Management Survey (FIMS) 1995: A Survey of Manure, Commercial Fertilizer and Commercial Pesticide Management Practices on Canadian Farms.* Statistics Canada, Agricultural Division, Ottawa (Ont.).

8. Soil Cover

SUMMARY

*Agricultural soil that is left unprotected and exposed to the elements (*bare soil*) is susceptible to degradation processes such as wind and water erosion, loss of organic matter, breakdown of soil structure and loss of fertility. The amount of time that soil is left bare depends on a variety of factors such as the type of crop, the amount of vegetative growth and the tillage practices employed. The Soil Cover Indicator summarizes the number of days of the year that agricultural soils are covered. An increase in the number of soil cover days over time indicates an improvement and a declining likelihood that soils will become degraded or contribute to degradation of the surrounding environment.*

Between 1981 and 2001, average levels of soil cover in Canada increased by over 5%. This improvement came primarily as a result of the widespread adoption of reduced tillage *and the decreased use of summerfallow in the Prairies. Increases in soil cover associated with reduced-tillage practices were offset to a considerable degree by cropping intensification (shifts from perennial to annual crops) and by increases in the area of crops such as potatoes, canola and soybeans, which produce inherently less* crop residue.

AUTHORS:
E. Huffman,
D. Coote,
J.Y. Yang and
F. Chen

INDICATOR NAME:
Soil Cover Indicator

STATUS:
National coverage, 1981 to 2001

THE ISSUE

Bare soil is more susceptible to soil degradation processes such as wind and water erosion, loss of organic matter, breakdown of soil structure and loss of fertility. A variety of factors influence the proportion and the amount of time that soil is left bare over a production cycle, including the following: the type of crop, the amount of vegetative growth and the tillage practices employed. Most perennial field crops such as hay offer good soil coverage year-round, while annual row crops such as cereals leave soil exposed at particular times such as planting. Other annual crops such as pulses (beans, peas, etc.) and oilseeds (canola, flax, etc.) tend to produce lower residue levels, leaving more soil exposed. Soil productivity and climatic or weather conditions also affect soil cover by influencing the amount of vegetative growth, and thus the amount of crop residue available as cover over the fall, winter and spring. The tillage method also influences the amount of soil cover, as some tillage practices turn most of the crop residue into the soil to leave a clean surface for seeding (referred to as "conventional tillage"), while "conservation tillage" leaves more crop residue on the soil surface, increasing soil cover.

Increasing the amount of soil cover in an agroecosystem has a number of benefits:

- offering protection against wind and water erosion;
- adding organic matter to the soil, which helps to maintain soil health;
- promoting carbon sequestration in soil, which helps to reduce levels of atmospheric carbon dioxide; and
- providing better wildlife habitat, which supports biodiversity.

THE INDICATOR

The Soil Cover Indicator summarizes the number of days per year that agricultural soils are covered in a typical crop production cycle. A "soil cover day" can be achieved with 100% cover for one day, 50% cover for 2 days, 10% cover for 10 days, and so on. The indicator considers the soil cover provided by crop canopy, crop residues on the soil surface and snow. As an example, a perennial hay crop typically has over 300 soil cover days per year, since there is very little soil exposed at any time. By contrast, a soybean crop in an area of low snowfall and without a *winter cover crop* may have less than half of that.

The indicator results are expressed in both the mean annual number of soil cover days (SCD), as well as the proportion of cropland falling into each of five classes of soil cover days per year (SCD/yr), for each census year between 1981 and 2001. These soil cover classes are defined as follows: very high (325 or higher SCD/yr), high (300 to 324 SCD/yr), moderate (275 to 299 SCD/yr), low (250 to 274 SCD/yr) and very low (249 or less SCD/yr). An increase over time in the number of soil cover days or in the proportion of land in the high cover classes indicates an improvement and a declining likelihood that soils will become degraded or contribute to degradation of the surrounding environment. The performance objective for this indicator is to have a steadily increasing trend in soil cover days, and ultimately 365 soil cover days under all cropping systems.

■ CALCULATION METHOD

The indicator is based on an index of soil cover that estimates the number of days in a year that there will be soil cover under each typical combination of crop and tillage. These tillage practices relate to the Census of Agriculture definitions for conventional tillage, conservation tillage and no-till. For example, conventional tillage is defined as tillage that "incorporates most of the crop residue into the soil" and corresponds to *moldboard plowing* and/or discing. Conservation tillage "retains most of the crop residue on the surface" and involves the use of equipment that reduces the amount of disturbance of the soil surface or the use of fewer passes with a conventional cultivator. No-till denotes that no tillage is done prior to planting.

In estimating the number of soil cover days, we established an annual calendar of "typical" field operations, with resultant soil cover, for each crop and tillage system in each ecological region. We then multiplied the percentage soil cover by the number of days between operations to provide the number of SCD in each phase, then summed the number of SCD that accumulate between planting one year and planting the next year. The soil cover account includes:

- the days on which significant changes occur in soil cover (e.g. at planting, harvesting and tillage) and the percentage of soil cover upon completion of the operation;
- canopy changes between planting, full canopy and harvest;
- the *decomposition* of residue;
- the total number of days of snow cover;
- the removal of straw through baling and burning;
- multiple cuts and grazing on hay and pasture.

Table 8-1: Average number of soil cover days and proportion of cropland in various soil cover classes, 1981 to 2001

	Soil Cover Days														
Province	**Area-weighted mean annual soil cover days (SCD)**					**Very High (≥325 SCD/yr)**					**High (300 – 324 SCD/yr)**				
	81	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**
British Columbia	284	293	294	295	295	0	1	0	1	1	24	48	54	55	54
Alberta	279	282	286	290	292	0	0	0	0	0	17	27	34	44	57
Saskatchewan	258	263	272	278	278	0	0	0	0	0	0	0	1	6	10
Manitoba	274	278	284	286	288	0	0	0	0	0	6	11	10	13	18
Ontario	268	269	273	280	281	1	3	1	2	4	11	14	14	20	14
Quebec	306	307	306	307	304	30	35	32	32	31	36	35	32	32	27
New Brunswick	324	328	326	327	325	58	69	63	65	67	38	25	32	31	21
Nova Scotia	326	329	330	331	330	72	78	76	78	76	20	15	17	19	16
Prince Edward Island	286	289	290	290	291	0	0	0	0	0	14	25	21	14	21
Newfoundland and Labrador	291	322	318	334	328	0	59	32	85	58	28	23	59	14	39
Canada	**272**	**275**	**281**	**285**	**286**	**3**	**3**	**2**	**3**	**3**	**10**	**15**	**17**	**23**	**29**

The amount of time associated with each proportion of soil cover was then calculated and summed to give the total number of days of soil cover for the year. About 2700 soil-cover-day tables were needed to account for all crops and ecoregions in Canada. Data for 90% of the crop area were drawn from field studies and many were verified by local field staff. For very small areas or rare crops, estimates sometimes had to be derived from known values for similar areas, crops and management.

On average, soil cover in Canada increased by 5%, from 272 SCD in 1981 to 286 SCD in 2001.

The index was then applied to Soil Landscape of Canada polygons, using crop area and tillage practice data obtained from the Census of Agriculture for 1981, 1986, 1991, 1996 and 2001. The area in each crop–tillage combination was multiplied by the appropriate number of soil cover days and a weighted average for all crops was calculated for each landscape polygon, as well as for larger spatial units such as provinces.

■ LIMITATIONS

A number of assumptions and limitations are inherent in the methodology. For example, the use of "typical" cropping practices and long-term climatic means (for snow cover, planting and harvest dates) mean that local variations in cropping practices, dates and weather conditions are not accounted for. However, the greatest limitation is that polygon-average tillage distributions are used for all crops equally and thus differences in the use of conservation tillage practices between crops are not incorporated. This is an ongoing concern and a number of studies and initiatives are being carried out to address the problem. Similarly, since conservation tillage and no-till systems have only come into wide use in the past 15 to 20 years and census reporting of tillage practices began in 1991, for this study we assumed that "conventional" tillage was used on both crops and summerfallow in 1981 and 1986.

■ RESULTS

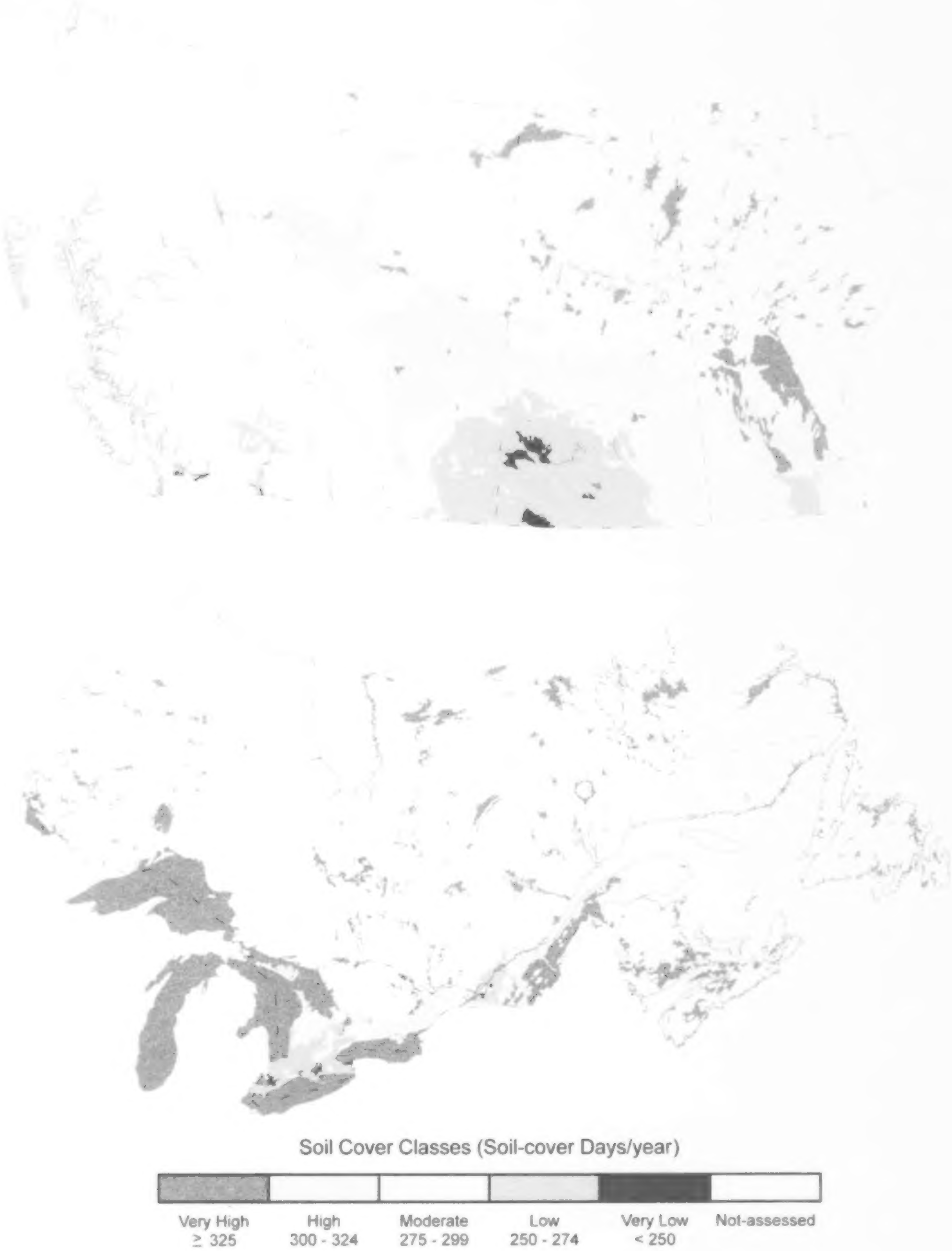
Estimates of the mean annual number of soil cover days and the proportion of cropland in each of the five soil cover classes per year, for each province and for Canada, are given in Table 8-1, providing an overview of soil cover trends over the period from 1981 to 2001. Figure 8-1 shows the geographical distribution of the cropland in the five soil cover classes in 2001.

Canada: On average, soil cover in Canada increased by 5%, from 272 SCD in 1981 to 286 SCD in 2001. The rate of increase was approximately 2% per intercensus period

Share of Cropland in Different Soil Cover Classes (in %)

Moderate (275 – 299 SCD/yr)					Low (250 – 274 SCD/yr)					Very Low (<250 SCD/yr)				
81	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**
53	34	32	27	29	17	13	11	9	14	6	4	3	8	2
42	33	29	28	22	29	30	35	14	21	12	10	2	14	0
28	40	43	48	42	26	28	50	21	45	46	32	6	25	3
32	50	67	69	67	61	39	23	15	15	1	0	0	3	0
31	26	35	33	39	32	31	32	29	40	25	26	18	16	3
18	14	21	20	23	15	15	15	13	19	1	1	0	3	0
4	6	5	4	12	0	0	0	0	0	0	0	0	0	0
7	6	7	2	8	1	2	0	1	0	0	0	0	0	0
67	57	60	82	79	19	18	19	4	0	0	0	0	0	0
60	15	2	1	3	12	3	7	0	0	0	0	0	0	0
33	**36**	**39**	**40**	**37**	**30**	**28**	**37**	**18**	**30**	**24**	**18**	**5**	**16**	**1**

Figure 8-1: Soil Cover on cultivated land in Canada, under 2001 management practices


Soil Cover Classes (Soil-cover Days/year)
Very High
≥ 325
High
300 - 324
Moderate
275 - 299
Low
250 - 274
Very Low
< 250
Not-assessed

between 1981 and 1996 and levelled off between 1996 and 2001. A national trend of improving soil cover between 1981 and 2001 is reflected in the dramatic increase in the proportion of cropland in the high soil cover category. Although the proportion in the very high cover class held steady at about 3% throughout the period, the proportion in the high cover category increased from 10% of cropland in 1981 to 29% in 2001. National values are driven primarily by changes in the Prairie Provinces, masking some of the provincial and regional variation.

British Columbia: Mean annual soil cover increased by 4% (from 284 to 295 SCD) over the 20-year period, with most of the increase occurring between 1981 and 1986. The increase continued between 1986 and 2001, but at a very small and declining rate. The proportion of cropland in the highest soil cover category remained at 1%, but the proportion in the high cover class increased from 24% to 54%, accompanied by a decrease in the lower classes. Considerable variation in soil cover change occurred within the province, with the Lower Mainland showing a 2% increase in SCD, the Interior a 3% increase and the Peace River district a 5% increase.

Alberta: Overall, the province showed a 5% increase in soil cover between 1981 and 2001, increasing from 279 SCD to 292 SCD, with a fairly consistent change between each census year. Alberta had no cropland in the very high cover class in any year, but the proportion of cropland in the high cover class increased from 24% to 54%, and the proportion of cropland in the very low cover category declined from 12% to 0%. The southeastern region of the province (*Brown Soil* zone) showed a 4% increase in soil cover, while the change in the central region (Dark Brown and *Black Soil* zones) was about 6% to 7%. As in British Columbia, soil cover in the Peace River area increased by 5%.

Saskatchewan: This province posted one of the highest average increases in soil cover at 7% (from 258 SCD to 278 SCD). The largest increases occurred between 1986 and 1991 (3%) and between 1991 and 1996 (2%), compared with an increase of less than 1% between 1996 and 2001. Increases ranged from 4% in the southwest to between 6% and 7% in the north and the east. None of the cropland had a very high soil cover rating, but the proportion in the high cover category increased from 0% to 10% and the moderate cover class increased from 28% to 42%. Meanwhile the very low soil cover class declined from 46% to 3% of cropland during the study period.

Manitoba: Soil cover in this province increased from 274 SCD to 288 SCD (5%) between 1981 and 2001, with the greatest increases occurring between 1981 and 1991. Although still positive, the rate of change has declined since 1991. The southwest portion of the province showed an increase of 6%, but the provincial average was reduced considerably by an average change of only 3% in the Lake Winnipeg Plain. As in the other Prairie Provinces, no cropland fell into the very high cover class. Nonetheless, the proportion of cropland in the high cover category tripled, from 6% to 18%, and the moderate cover class increased from 32% to 67%.

Ontario: The proportion of cropland in the very high and high soil cover classes increased slightly between 1981 and 2001, from 1% to 4% and from 11% to 14% respectively. The most significant change came from the very low cover class, which decreased from 25% to 3%. The 5% average increase in soil cover (from 268 SCD to 281 SCD) is similar to the change recorded in British Columbia, Alberta and Manitoba, but the greatest rate of change occurred later in time (between 1991 and 1996) than in the western provinces. The highest rate of change (7%) occurred in southwestern Ontario, whereas the central portion of the province showed an average increase of 3% and the eastern part a 1% decrease.

Quebec: Very high levels of soil cover characterized about 30% of Quebec cropland throughout the period under study. A decrease from 36% to 27% in cropland with high soil cover coincided with increases in the area with moderate cover (from 18% to 23%) and low cover (from 15% to 19%). Average soil cover in Quebec was higher than in Ontario and the western provinces for all census years, but a slight and steady decline occurred over the period, from 306 SCD in 1981 to 304 SCD in 2001 (-1%). This overall decline masks a slight improvement that occurred between 1981 and 1986. Only the Eastern Townships and the south shore regions showed an increase (1%) over the 20-year period.

New Brunswick: Results are similar to Quebec, with an increase between 1981 and 1986 and then a decline to 2001. However, the overall 20-year change consisted of an increase of less than 1%. The provincial average reflects a very small decrease in soil cover in the primary agricultural areas (St. John River Valley and the Suffolk region) and a small improvement in the rest of the province. The proportion of cropland in the very high cover class increased from 58% to 67%, but the amount in the high cover category decreased from 38% to 21% and the amount in the moderate cover category increased from 4% to 12%. No cropland fell into either the low or the very low soil cover class.

Nova Scotia: This province had the highest proportion of cropland in the very high soil cover category, with an increase from 72% to 76% between 1981 and 2001. Soil cover in Nova Scotia increased by just over 1% between 1981 and 2001, with most of the increase coming between 1981 and 1986. Soil cover increased by less than 1% in the Annapolis Valley, slightly more than 1% in the Truro area and about 2% in the southern coastal areas.

Changes resulted from a decrease in the proportion of cropland under conventional tillage, a decrease in the area of summerfallow and increases in conservation tillage.

Prince Edward Island: No cropland fell into the very high or the very low soil cover class, and the amount in the low cover category fell from 19% to 0% during the 20-year study period. This was reflected in increases in the high soil cover class (14% to 21%) and the moderate class (67% to 79%). Provincially, soil cover increased by five SCD between 1981 and 2001.

Newfoundland and Labrador: This province had the greatest increase in soil cover on cropland between 1981 and 2001 (12%), along with the largest increase in the very high cover class, which went from 0% to 58%. There was a dramatic increase between 1981 and 1986, a slight decline between 1986 and 1991, another increase between 1991 and 1996 and a decline again between 1996 and 2001.

■ INTERPRETATION

As noted previously, changes in soil cover account for two factors related to cropping practices: changes in tillage practices such as the adoption of conservation tillage and no-till and changes in the area of crops. Thus, although the adoption of conservation practices may increase soil cover by up to 100% or more for a specific crop, a shift from no-till on a high-residue crop, such as corn, to no-till on a low-residue crop, such as soybeans, can result in a decrease in soil cover.

Canada: A national improvement in soil cover between 1981 and 2001 is reflected in the dramatic increase in the proportion of cropland in the high soil cover category and the decline in the very low cover category. These changes resulted from a decrease in the proportion of cropland under conventional tillage, a decrease in the area of summerfallow and increases in conservation tillage and no-till and in the area of forage crops. An increase in cropland area and shifts to lower-cover crops such as canola, potatoes and soybeans put downward pressure on soil cover change.

British Columbia: The proportion of cropland in the high soil cover class increased at the expense of the lower cover classes. This positive change came from a 42% reduction in summerfallow, a 13% increase in forage and the adoption of reduced-tillage practices on 34% of cropland and 37% of summerfallow. Factors countering the positive effect included a 10% increase in cropland, a 38% and 50% reduction in the area of higher-residue spring and winter cereals respectively and an expansion of the area under the lower-residue crops of peas, beans, lentils, berries and grapes.

Alberta: Soil cover increased in this province, primarily owing to the elimination of conventional tillage on 63% of cropland and on 61% of summerfallow. In addition, summerfallow area and flax area (low-cover land uses) decreased by 44% and 61% respectively and forage area increased by 49%. As elsewhere in Canada, gains in soil cover were partially offset by other changes in cropping patterns, most notably a 15% increase in cropland area, a 72% increase in canola, large increases in potatoes, peas, beans and lentils, a 65% decrease in winter cereals and an 8% decrease in spring cereals.

Saskatchewan: The increases in the higher soil cover classes in Saskatchewan resulted from the adoption of reduced-tillage systems on 68% of cropland and on 53% of summerfallow, a 53% reduction in summerfallow area and a 60% increase in forages. The improvement in soil cover was attained despite a 31% expansion of cropland, large increases in canola, flax, potatoes, peas, beans and lentils, an 11% decrease in spring cereals and a 34% decrease in winter cereals.

Manitoba: The observed increases in soil cover can be attributed to a 57% reduction in summerfallow, a 38% reduction in flax, a 41% increase in forages and the use of reduced-tillage on 46% of cropland and on 50% of summerfallow. Decreases in the area of higher-residue crops (spring cereals, -17%; grain corn, -50%) and increases in the area of lower-residue crops (canola, up 192%; potatoes, up 90%; peas, beans and lentils up 174%) had a negative effect on soil cover between 1981 and 2001.

Ontario: The increases in the proportion of cropland in the moderate to very high soil cover classes resulted from the elimination of conventional tillage on 48% of cropland and from a 50% reduction in corn silage area. These changes would have contributed a higher gain in soil cover, but a shift away from forages (-24%), grain corn (-8%) and spring cereals (-22%) to soybeans (+227%) depressed the amount of available residue.

Quebec: Factors contributing to the overall shift in cropland from the high soil cover class to the moderate and low cover levels include an 18% increase in the area of cropland under conventional tillage, a decrease of 36% in forage area, an increase from 2000 hectares to 156,000 hectares under bean production, a 34% increase in vegetable area and a 300% increase in berry cultivation. Increases in higher residue grain corn and spring cereal area (164% and 45%, respectively) and a 38% decrease in silage corn also pushed up soil cover values.

New Brunswick: The increases in the amount of cropland in the very high and moderate cover categories are explained by various land use changes: a 28% increase in spring cereals, a 250% increase in winter cereals, a 70% decline in vegetables, a 16% increase in cropland, a 15% decrease in forages, an 8% increase in potatoes and a 6% increase in conventionally tilled cropland.

Nova Scotia: The slight changes observed in Nova Scotia came as a result of a 22% decrease in the area of cropland under conventional tillage, while increases in cropland (14%), grain corn (50%), potatoes (34%) and berries (156%) and decreases in forages (-18%), spring cereals (-25%) and winter cereals (-43%) also played a role.

Prince Edward Island: The land use changes that had a positive effect on soil cover include a decrease in cropland under conventional tillage (-11%), decreases in silage corn (-39%) and vegetables (-40%) and increases in grain corn (750%) and winter cereals (125%). These were somehow counteracted by negative influences from increases in cropland (11%), potatoes (68%) and soybeans (from 42 to 6600 hectares: up by 6600%) and decreases in forages (-20%) and spring cereals (-12%).

Newfoundland and Labrador: The increase in the high and very high cover classes resulted from upturns in total cropland area (85%), forages (19%), spring cereals (382%) and winter cereals (1400%), along with decreases in conventionally tilled cropland (-7%) and in the area of potatoes (-24%) and vegetables (-19%).

RESPONSE OPTIONS

The national increase in soil cover shows a high rate of change in the early to mid-1990s and a much more modest rise in the latter part of the decade. This suggests that the rate of adoption of conservation tillage practices is reaching a plateau and that further expansion may not keep up with the negative influence of cropping system changes. Changes in cropping patterns that are slowing the improving trend of soil cover in Canada, such as expanding production of pulse crops, oilseeds and potatoes, can be expected to continue as producers diversify and follow the markets. To increase the level of soil protection, it is therefore necessary to expand and improve techniques for increasing and maintaining crop canopy and residues.

It appears that there is still opportunity for expansion of reduced-tillage systems, especially no-till in British Columbia, Manitoba, Quebec and the Atlantic Provinces, where it was used on less than 15% of cropland in 2001. There are technical and financial concerns related to the adoption of reduced tillage, and although this type of system cannot be used on all crops, continued expansion is expected, albeit at a lower rate than over the past 25 years.

Of perhaps greater importance in view of the growing area of low-residue crops such as potatoes, canola, sugar beets, soybeans and horticultural crops is the use of practices to enhance soil cover in these cropping systems. Planting a "green manure" crop or a winter cover crop where feasible promptly after harvesting would provide a greater degree of soil cover over the long period between harvesting and planting. Similarly, the use of cereals or perennial grass in the interrow area of perennial horticultural crops would increase soil cover.

The soil cover situation should eventually receive a boost from research on the development of suitable companion and over-winter crops, cold-germination varieties of crops for use under no-till, equipment to better maintain surface residues while performing production operations satisfactorily, and perhaps even crops with a greater mass of more durable foliage.

REFERENCES

Dumanski, J. , L.J.Gregorich, V. Kirkwood, M.A. Cann, J.L.B. Culley and D.R. Coote, 1994. *The Status of Land Management Practices on Agricultural Land in Canada: Compiled From the 1991 Canada Census of Agriculture.* Technical Bulletin 1994-3E, Agriculture and Agri-Food Canada, Ottawa (Ont.).

Huffman, E. , R.G. Eilers, G. Padbury, G. Wall, and K.B. MacDonald, 2000. *Canadian Agri-Environmental Indicators Related to Land Quality: Integrating Census and Biophysical Data to Estimate Soil Cover, Wind Erosion and Soil Salinity.* Agriculture, Ecosystems and Environment. 81(2): 113-123. http://cgrg.geog.uvic.ca//abstracts/HuffmanCanadianA.html

Lobb, D.A., E. Huffman, and D. Reicosky, 2005. "*Importance of Information on Tillage Practices in the Modelling of Environmental Processes and in the Use of Environmental Indicators*". In Proceedings of OECD Expert Meeting on Farm Management Indicators and the Environment, Palmerston North, New Zealand, March 8 – 12, 2004. OECD, Paris (France).

Prairie Farm Rehabilitation Administration (PFRA), 2003. *Managing Crop Residues on the Prairies.* Crop Residue Survey on the Prairies (online document). Agriculture and Agri-Food Canada, PFRA, Regina (Man.). www.agr.gc.ca/pfra/soil/residue_e.htm

Statistics Canada, 2005. *Census of Agriculture.* Statistics Canada, Ottawa (Ont.). www.statcan.ca/english/sdds/3438.htm

Steiner, J.L., H.H. Schomberg, and P.W. Unger, 1999. "*Predicting Crop Residue Decomposition and Cover for Wind Erosion Simulation*". In Wind Erosion, an International Symposium/Workshop (online proceedings of the 1997 International Wind Erosion Symposium). U.S. Department of Agriculture, Agricultural Research Service, Wind Erosion Research Unit, Manhatten (Kansas). www.weru.ksu.edu/symposium/proceedings/steiner.pdf

9. Nitrogen Use Efficiency

AUTHORS:

C. F. Drury,
J.Y. Yang,
R. De Jong,
T. Huffman,
V. Kirkwood,
X. M. Yang
and K. Reid.

INDICATOR NAME:

Residual Soil Nitrogen

STATUS:

National coverage, 1981 to 2001

■ SUMMARY

Residual soil nitrogen (RSN) is the amount of nitrogen that has been applied to soil but not removed in the harvested portion of crops. The Residual Soil Nitrogen Indicator was calculated as the difference between all nitrogen (N) inputs (fertilizer, manure, biological fixation and atmospheric deposition) and all nitrogen outputs (N removed in crop harvest, N lost through ammonia volatilization and N lost through denitrification*), for each of the five Census years from 1981 to 2001.*

On average over the five Census years, most of the farmland in Canada (63%) was in the very low (24%) and low (39%) RSN classes. RSN remained relatively stable between 1981 and 1996 (16.1–18.1 kg of N per ha) and then dramatically increased by about 50% to 27.6 kg of N per ha in 2001. This rise was mainly due to an increase in pulse crop acreage (i.e. greater natural biological fixation) without a concurrent decrease in fertilizer application and to significantly lower crop yields and reduced N uptake as a result of climatic constraints (droughts) which were prevalent in many regions in Canada in 2001.

■ THE ISSUE

Nitrogen is an essential nutrient required by all crops. Legumes (e.g. soybean, alfalfa, red clover) fix nitrogen from the atmosphere, but non-leguminous crops (e.g. corn, cereal crops, potatoes) require applied nitrogen for optimal growth and yield (Drury and Tan 1995). Nitrogen is added to these non-leguminous crops through fertilizer and manure, atmospheric deposition and mineralization of crop residues and soil organic nitrogen. Nitrogen must be properly managed to reduce costs to farmers (from purchasing, transporting and applying mineral fertilizers), to maximize productivity and to curb losses of this key nutrient from agricultural land to the environment.

Losses occur because not all of the applied nitrogen is used by the crop, and some *inorganic* nitrogen inevitably remains in the soil at the end of the growing season (residual soil nitrogen). Environmental risks may be associated with unduly large surpluses in the soil, particularly in *humid regions*. Most of the residual inorganic nitrogen, which is in the form of nitrate, is water soluble and is susceptible to leaching through the soil into groundwater or to loss through tile drainage into ditches, streams and lakes. High nitrate levels in surface waters contribute to algae growth and eutrophication, and they may pose a threat to human health in the case of drinking water (Chambers et al. 2001). Under anaerobic conditions, nitrate can also be lost (through denitrification) from the soil to the atmosphere in the form of nitric oxide, nitrous oxide (a potent greenhouse gas) and nitrogen gas.

Management of nitrogen is further complicated by climatic conditions (drought, excess rain, early frost, etc.) and other soil physical and chemical factors, which can limit crop growth and therefore nitrogen uptake. This can in turn lead to further increases in the amount of residual soil nitrogen at the end of the growing season.

■ THE INDICATOR

The Residual Soil Nitrogen (RSN) Indicator was developed to estimate the quantity of nitrogen in the soil that is provided in excess of crop requirements and therefore remains in the field after harvest (MacDonald, 2000). It is the difference between the amount of nitrogen that is available to the growing crop from all sources and the amount removed in the harvested crop portion under average conditions along with gaseous losses to the atmosphere.

The indicator in itself does not give any insight into the environmental effects of various levels of RSN in different environmental settings. Surplus nitrogen may pose a risk to the environment, but this risk is also sensitive to other factors such as soil type and climatic conditions. Thus, a second agri-environmental indicator, the Indicator of Risk of Water Contamination by Nitrogen (see Chapter 17), links RSN to climatic conditions in order to assess the likelihood of nitrogen moving out of the agricultural system and into water resources.

The RSN Indicator is expressed as the proportion of agricultural land that falls into each of five classes (see Table 9-1). The performance objective for this indicator is to increase the share of Canadian farmland in classes associated with minimal nitrogen accumulation over time, typically Classes 1 and 2.

■ CALCULATION METHOD

The RSN Indicator was calculated, at the Soil Landscape of Canada (SLC) level, using the standardized Canadian Agricultural Nitrogen Budget model (CANB Version 2.0). This model uses a nitrogen budget to calculate annual residual soil nitrogen as the difference between nitrogen inputs and outputs, divided by the total area of farmland in the SLC polygon.

Nitrogen input is the total nitrogen added to farmland during the growing season from chemical fertilizers applied to crops; manure applied to crops and pasture; biological fixation of nitrogen by leguminous crops; and the total amount of wet and dry nitrogen deposition from the atmosphere. It is assumed that only 50% of total manure nitrogen is available for crops, while another 50% is not readily available (35% as organic nitrogen and 15% lost during the storage and application processes).

Table 9-1: Residual Soil Nitrogen (RSN) Indicator Classes

Class	Description	Range of Values (kg N ha^{-1})
1	Very low RSN	0 – 10
2	Low RSN	10 – 20
3	Moderate RSN	20 – 30
4	High RSN	30 – 40
5	Very high RSN	Greater than 40

kg N ha^{-1} = kilograms of nitrogen per hectare

Nitrogen output is the total nitrogen removed from farmland annually in the harvested portions of crops and pastures, combined with gaseous losses to the atmosphere, which occur mainly through denitrification but also through ammonia volatilization.

The main data inputs are the acreages for all the major agricultural crops and their associated crop yields, as well as the type and number of livestock. Since these data are collected every five years through the Census of Agriculture, all input and output calculations are based on information for a particular Census year. Consequently, the output from this indicator reflects stepwise changes in soil and crop management practices at the SLC level. Various coefficients and assumptions, based on experimental values and expert opinion, are incorporated into the calculations (e.g. animal excretion rates and N contents [American Society of Agricultural Engineers, 2003], biological fixation rates, provincially recommended N application rates, and N in harvested yields). It was also assumed that 1.25% of all N inputs from fertilizer, manure and biological fixation, were lost as *nitrous oxide* (N_2O) through denitrification (Intergovernmental Panel on Climate Change, 2001). Denitrification also results in molecular nitrogen (N_2) loss from the soil. However, the N_2O: N_2 ratio is quite variable and at this time, we do not have enough data to estimate N_2 losses.

■ LIMITATIONS

The methodology used to calculate the Residual Soil Nitrogen Indicator has several limitations. While the indicator can be used to identify areas that are at risk for nitrogen accumulation and losses to the environment, it is based upon many assumptions and approximations. The results are estimates, and they should be interpreted accordingly.

One of these assumptions involves reliance on official provincial recommendations for nitrogen input, which may not reflect the most recent changes and which are not adjusted for factors such as the nitrogen released from manure applications in previous years. We also assumed that a fixed proportion (15%) of the nitrogen contained in manure would be lost during storage and handling. However we know that nitrogen losses during manure storage vary with manure source, storage method and manure form (liquid, solid, compost). In time, better data and more dynamic models may become available, enabling us to make better estimates of nitrogen inputs, for example, by including differences in manure types and storage methods.

Although soil nitrogen mineralization (conversion of organic N to inorganic N) and immobilization (conversion of inorganic N to organic N) occur on a seasonal basis, it is assumed that the soils are in a steady state with no net change in soil organic carbon (C) and organic nitrogen (N) from one year to the next. If a management practice is adopted that favours C and N sequestration, then some of the RSN will go into the organic N pool until a new steady-state organic C and N value is reached. During this process, RSN would over-estimate the amount of mineral N remaining in the soil following harvest. This will be examined in greater detail in future studies.

On average, most of the farmland in Canada (63%) was in the very low (24%) and low (39%) RSN classes.

Another obvious limitation in the application and interpretation of results from the RSN indicator is the low frequency of Census data (once every 5 years). This poses a problem particularly with respect to yield variability resulting from year-to-year climatic variation. In the coming years, complementary approaches will be evaluated to better estimate RSN values and address the issue of indicator sensitivity to severe climatic variability (and resultant decreases in crop yields) coinciding with a Census year.

■ RESULTS

Estimates of the proportion of farmland in each RSN class for each province and for Canada are provided in Table 9-2. Figure 9-1 shows the geographical distribution of the farmland in the five RSN classes in 2001. For simplicity, unless otherwise specified, the results provided below refer to the average proportions of farmland in various RSN classes observed over the 20 years of the study period (five Census years: 1981, 1986, 1991, 1996, and 2001). Refer to Table 9-1 for details on the RSN classes.

Canada: On average, most of the farmland in Canada (63%) was in the very low (24%) and low (39%) RSN classes. However, a fairly continuous decline occurred in the proportion of farmland in these two classes, mostly with a concurrent increase in the moderate RSN class. Between 1981 and 1996, at most 14% of Canadian farmland fell in the high and very high RSN classes. However, in 2001 the proportion of farmland in these two classes increased significantly, to 43% (high: 28%; very high: 15%).

British Columbia: Similar to the national trends, 68% of the farmland in BC was in the very low and low RSN classes, while only 13% of farmland was in the high and very high classes. Here again, there was a gradual decline in the percentage of farmland in the very low RSN class coupled with an increase in the moderate class from 1981 to 2001.

Prairies: Alberta and Saskatchewan exhibited similar trends with, on average, high proportions of farmland in the very low and low RSN classes (AB: 83%; SK: 70%). However, these proportions changed in 2001 with a significant increase in the proportion of farmland in the moderate and high RSN classes combined (AB: 44%; SK: 80%). In Manitoba, the situation is different, with an average of only 5% of farmland in the very low and low RSN classes. On average, most of the farmland in Manitoba (84%) is in the high and very high RSN classes combined, with 72% of farmland in the very high RSN class for 2001.

Table 9-2: Share of Farmland in various Residual Soil Nitrogen Classes, 1981 to 2001

Share of farmland in different RSN classes (in %)

Province	Very Low					Low					Moderate					High					Very High				
	81	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**
BC	43	37	33	37	26	32	35	32	32	32	13	17	23	19	25	6	6	6	5	11	7	5	7	6	6
AB	43	53	42	43	26	50	44	46	41	30	7	2	12	16	34	0	0	0	0	10	0	0	0	0	1
SK	14	32	30	22	2	75	56	48	57	16	10	10	18	18	32	1	2	3	2	48	0	0	1	0	3
MB	1	2	0	0	0	4	10	2	2	1	10	10	13	15	9	42	46	38	63	17	43	32	46	20	72
ON	8	11	9	4	1	24	55	23	19	5	47	34	63	68	13	20	0	2	5	29	0	0	3	3	52
QC	28	1	6	41	8	40	43	39	35	25	18	26	39	8	48	3	19	6	2	5	11	11	10	13	14
NB	0	0	0	2	0	42	0	1	18	16	34	10	24	43	29	13	35	35	15	22	10	55	41	22	33
NS	9	0	0	56	2	65	0	11	10	5	10	47	49	7	38	2	27	14	5	19	14	26	26	23	37
PEI	0	0	0	3	0	35	19	0	48	0	61	81	56	49	8	3	0	44	0	53	0	0	0	0	39
NL	32	0	25	15	3	13	5	4	3	15	10	6	10	10	22	1	2	0	4	9	44	87	60	68	51
Canada	**22**	**32**	**28**	**26**	**10**	**52**	**45**	**39**	**41**	**18**	**13**	**10**	**20**	**20**	**29**	**7**	**8**	**7**	**9**	**28**	**6**	**5**	**7**	**3**	**15**

Ontario: On average, most of the farmland in Ontario (45%) was in the moderate RSN category whereas 23% was in the high and very high classes. There was a general downtrend in areas of very low and low RSN classes over time, as well as a dramatic increase in the high and very high classes in 2001 (combined: 81% of farmland).

Quebec: On average, most of the farmland in Quebec (53%) was in the very low and low classes, and only 19% in the high and very high classes. However, there was a gradual decrease in the low class and a gradual increase in the moderate class over time. Unlike other provinces, which had dramatic increases in the high and very high classes in 2001 versus other years, there was only a 4% increase in these higher classes from 1996 to 2001 in Quebec.

Atlantic: On average, between 15% and 31% of the farmland in New Brunswick, Nova Scotia and Prince Edward Island (PEI) was in the very low or low RSN classes. There was a significant increase in the high and very high classes between 1996 and 2001 (NB: 18%; NS: 28%; PEI: 92%). Newfoundland and Labrador, on the other hand, had most of the land in the high and very high classes from 1986 to 2001 (60 to 89%).

INTERPRETATION

Unless otherwise specified, the N input, N output and RSN values referred to in the following text are averages for the five Census years.

Canada: N input and N output both increased by a similar amount from 1981 to 1996 due to increases in fertilizer sales, manure produced by livestock and increased acreages of legume crops as well as increased yields (N outputs). Nitrogen outputs from farmland are influenced by new technology, improved crop varieties and weather conditions. Climatic variability seems to be the main factor affecting yield variability, which significantly impacts N uptake and the amount of RSN at harvest.

In 2001, N input continued to increase whereas N output decreased compared to 1996. Over half (63%) of the observed RSN increase between 1996 and 2001 is explained by the increase in N inputs and about 37% by reduced N outputs. The increases of N input in 2001 were mostly due to increased acreages of legume crops that fix atmospheric N (and an accompanying decrease in wheat, barley, cereals and summerfallow), as well as increased livestock numbers, resulting in more manure N being applied to the land. The decrease of N outputs was caused mainly by decreased yields of a number of crops linked to adverse climatic conditions.

Figure 9-1: Residual Soil Nitrogen levels on farmland in Canada under 2001 management practices

Residual Soil Nitrogen Classes (kg N/ha)
0 - 9.9
10 - 19.9
20 - 29.9
30 - 39.9
≥ 40
Not-assessed

British Columbia: Nitrogen input increased but N output decreased slightly from 1981 to 2001. During that period, the amount of fertilizer sold in BC was relatively constant, increases in N input being mostly driven by the increase in manure N (mostly from poultry). Similar to the national trend, the crop area of wheat, barley and cereals decreased, while the area of pulse, forage and alfalfa increased.

Alberta: While Alberta has low N inputs and outputs in its agricultural sector, fertilizer sales and manure (cattle and pig) production increased dramatically over the 20-year period, contributing to a gradual increase in the proportion of land in the moderate RSN class (Table 9.2). Nevertheless, Alberta was the province with the lowest RSN value (12 kg N ha^{-1}) over the five Census years. There was also a decrease in wheat, cereals, flax and summerfallow acreages, and an increase in pulses, forages, potato, alfalfa and improved pasture acreages. At the same time, yield increases contributed to higher N output, which limited the increase in RSN.

Saskatchewan: Saskatchewan has the largest area of farmland in Canada, the lowest N input and fairly low animal densities. This resulted in the second lowest RSN values overall, although both nitrogen input and output increased gradually over the 20-year period studied. The N input increase is mainly explained by dramatic increases in fertilizer sales and manure production. In keeping with the national trend, crop areas increased for pulses, canola, hay and alfalfa, whereas the wheat area decreased.

Manitoba: Manitoba has the highest RSN of the Prairie Provinces (37 kg N ha^{-1}), mostly as a result of relatively high N inputs (81 kg N ha^{-1}). Nitrogen inputs also increased linearly from 1981 to 2001 due to increases in fertilizer sales, livestock numbers and manure nitrogen. Here again, crop areas increased dramatically for pulses and canola, with smaller increases in potatoes and alfalfa, and a decrease in the summerfallow area.

Ontario: Ontario has higher N inputs (112 kg N ha^{-1}) and outputs (87 kg N ha^{-1}) than the Prairie Provinces, and both inputs and outputs increased over the 20-year period under study. While fertilizer sales declined in Ontario from 1986 to 2001, N inputs rose overall, mostly due to higher biological fixation from increased soybean (20% each year) and alfalfa acreages as well as increased livestock numbers (manure N from poultry and hog operations). Increases of wheat areas were offset by a reduction in other cereal crops. Pasture areas also steadily declined.

Quebec: In Quebec, nitrogen inputs and outputs increased over time. N inputs (110 kg N ha^{-1}) and N outputs (84 kg N ha^{-1}) and RSN (26 kg N ha^{-1}) values in Quebec were similar to those in Ontario. Increases in N inputs were driven by continued increases in fertilizer sales and increases in manure resulting from higher poultry and hog numbers. Legume crop (pulse, soybean and alfalfa) acreages increased, whereas pasture areas decreased in Quebec.

Atlantic: High N inputs and comparatively low N outputs resulted in somewhat higher RSN values in New Brunswick, Nova Scotia and Newfoundland and Labrador compared to Alberta, Saskatchewan, Ontario and Quebec. N inputs increased over the 20-year period in all Atlantic Provinces and N outputs increased in New Brunswick and Newfoundland and Labrador between 1981 and 2001. N input increases were primarily attributable to higher livestock numbers (poultry and pig). Field crops increased in wheat, soybean, canola, forage and alfalfa acreages, whereas pasture and summerfallow areas decreased. In general, PEI has a medium N input and high N output leading to a lower RSN compared to the other Maritime Provinces. Here again, there was an increase in cereals, soybean, potato and alfalfa acreages while improved pasture decreased over the 20-year period. Newfoundland and Labrador posted the highest RSN values among all the provinces across all Census years. The RSN value for Newfoundland and Labrador exceeded 100 kg N ha^{-1} in 1986, 1996 and 2001. These high values reflect higher livestock numbers and the limited area of farmland available for manure application. For example in 2001, 75% of the N inputs were from manure and 21% from biological fixation by leguminous crops but only 2% was from applied N fertilizer and 1% from atmospheric deposition. Manure nitrogen inputs more than doubled between 1981 and 1986, and they continued to rise between 1991 and 2001. Crop types were dominated by pasture, which nonetheless decreased whereas hay and alfalfa acreages increased.

■ RESPONSE OPTIONS

Areas with high and very high levels of residual nitrogen (Classes 4 and 5) should be examined in more detail to determine the probable cause. Soil testing can be used to confirm the results. Where high levels of residual nitrogen are confirmed, steps should be taken to correct this situation, and beneficial management practices (BMP) employed to control or reduce the amount of residual nitrogen present in the soil at the end of the growing season. Regular soil testing, reduction of the N fertilizer application rate, improved N mineralization estimates and synchronization with N demand by crops represent other avenues for increasing nitrogen use efficiency. It is also necessary to consider N inputs from all legume crops when N fertilization recommendations are made. This is especially true for high nitrogen-fixing crops such as soybean and alfalfa. Cover crops can be used in areas that have high RSN levels, not only to remove nitrate present in the soil at the end of the growing season, but also to increase soil organic carbon levels and improve the physical quality of the soil (Drury et al. 1999).

In areas where high livestock density is a key contributing factor to high and very high RSN values (Lower Mainland region of BC, south-central Alberta, southern Ontario, the St. Lawrence Lowlands in Quebec and coastal lowland regions in Atlantic Canada), unless livestock numbers are reduced, or the land base available for manure application is increased, it may be necessary to investigate alternative methods of treating the manure or diverting it to other purposes, such as biogas production. Improved animal feeding efficiencies through better management practices and feed additives can also contribute to reduce nutrient loads by reducing the amount of N excreted in the manure. Reducing fertilizer application rates in areas with high manure application and/or leguminous crops is another management practice that could be used to a greater extent to lower RSN values.

■ REFERENCES

American Society of Agricultural Engineers (ASAE), 2003. *"Manure Production and Characteristics"*. Pages 683-685 in ASAE Standards 2003, 50th ed. ASAE-The Society for Engineering in Agricultural, Food, and Biological Systems. St. Joseph (Michigan).

Chambers, P.A., M. Guy, E.S. Roberts, M.N. Charlton, R. Kent, C. Gagnon, G. Grove, and N. Foster, 2001. *Nutrients and Their Impact on the Canadian Environment*. Environment Canada, Ottawa (Ont.).

Drury, C.F. and C.S. Tan, 1995. *Long-Term (35 Years) Effects of Fertilization, Rotation and Weather on Corn Yields*. Canadian Journal of Plant Science. 75: 355-362.

Drury, C.F., C.S. Tan, T.W. Welacky, T.O. Oloya, A.S. Hamill, and S.E. Weaver, 1999. *Red Clover and Tillage Influence on Soil Temperature, Moisture and Corn Emergence*. Agronomy Journal. 91: 101-108.

Intergovernmental Panel on *Climate Change (IPCC), 2001. Climate Change 2001: The Scientific Basis – Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (J.T. Houghton, et al, eds). Cambridge University Press, Cambridge (UK). www.grida.no/climate/ipcc_tar/wg1/index.htm

MacDonald, K.B, 2000. *"Residual Nitrogen"*. In McRae, T., Smith, C.A.S., and Gregorich, L.J. (eds). Environmental Sustainability of Canadian Agriculture; Report of the Agri-Environmental Indicator Project. Agriculture and Agri-Food Canada, Ottawa (Ont.). www.agr.gc.ca/env/naharp-pnarsa/

10. Energy Use Efficiency

AUTHORS:
A. Piau and
M. Korol

INDICATOR NAME:
Energy Use Efficiency Ratio

STATUS:
National coverage, 1981 to 2001

SUMMARY

Agriculture, like other human activities, requires energy as an input and turns out products that contain energy. Agricultural producers have an economic incentive to minimize energy inputs *(often associated with reduced environmental risks) as long as they can maintain or increase their agricultural (energy) outputs. The Energy Use Efficiency Ratio (*Energy Output *per unit of Energy Input) has been used to evaluate the energy use efficiency of the agricultural sector. The indicator shows that the Energy Use Efficiency Ratio for Canadian agriculture decreased by 3% between the two periods 1981-1985 and 1997-2001. During these two periods combined, the total energy input increased by 16% and energy output rose by 13%. Changes in the overall energy input are mostly due to increases in the energy inputs represented by diesel fuel and fertilizer. Energy outputs varied from year to year and between provinces, but they largely reflected a 31% decrease in wheat and a 169% increase in canola. Together, these two crops accounted for 53% of the total energy output in 1997-2001.*

THE ISSUE

In agriculture, energy inputs are used to power vehicles and farm machinery, manufacture equipment and chemicals (e.g. mineral fertilizers, pesticides) and perform other tasks. While much of this energy comes from outside the agricultural sector (e.g. from petroleum sources), some is supplied by the sector itself (e.g. feed for livestock production). Energy eventually leaves the agricultural system in the form of commodities such as cereals, horticultural crops and livestock, or through losses to the environment.

Sustaining today's highly mechanized agriculture, or increasing production on a fixed land base with limited natural soil fertility, typically requires increasing amounts of energy input (e.g. fertilizer use) and/or introducing new technologies (e.g. higher-yielding grain varieties) or management strategies (e.g. minimum and no-till practices). Changes in the amount of energy input or output can be short or long term, and are a reflection of changes in the following areas: technology or farm management practices, government policies that affect decisions on input use or output products, and weather patterns that affect yields (which can have significant impact on the energy output).

From an economic perspective, agricultural producers stand to benefit from using inputs as efficiently as possible, minimizing their direct costs and maximizing profit. In addition, more efficient or reduced input use is often associated with reduced environmental risk. For example, fossil fuels and nitrogen fertilizers are recognized as sources of greenhouse gas emissions. Understanding the amount and form of energy that is used and produced in agriculture, along with how these components are changing over time, provides some information on how the system is performing.

THE INDICATOR

The Energy Use Efficiency Ratio essentially consists of two sub-indicators. The first one—Energy Input—estimates the amount of energy contained in agricultural inputs. The second—Energy Output—estimates the amount of energy contained in agricultural products. An increase in Energy Input will generally imply a greater intensity of resource use and a higher level of environmental risk. Conversely, an increase in Energy Output, without a significant change in the mix of agricultural products, is a sign of improved productivity.

These two sub-indicators are combined to create a ratio (Energy Output per unit of Energy Input) which is used to evaluate energy use efficiency. By carefully examining the Energy Input and Energy Output measures, it is then possible to explain changes in the Energy Use Efficiency Ratio. The performance objective for this indicator is an Energy Use Efficiency Ratio that increases over time.

■ CALCULATION METHOD

The calculations for Energy Input, Energy Output and the Energy Use Efficiency Ratio (total Energy Output divided by total Energy Input) were carried out at the provincial and national levels for each year between 1981 and 2001. The results for 1981 to 1996 are from Weseen and Lindenbach (1998), but they have been adjusted to reflect the updated approach used for the 1997-2001 estimates. The results are reported for three time periods: 1981-1985, 1989-1993 and 1997-2001. This aggregation of the results into three five-year periods provides a more meaningful basis of comparison by smoothing out significant annual fluctuations in output values.

Understanding the amount and form of energy that is used and produced in agriculture, provides some information on how the system is performing.

The Energy Input component was evaluated using the methodology described in "Energy Use Trends in Canadian Agriculture" (Coxworth 1997). This method was modified in order to deal with a scarcity of information at the provincial level. The energy inputs included in the calculations consist of refined petroleum products (natural gas, gasoline, diesel fuel and natural gas liquids, e.g. propane and butane), electricity, energy used to produce mineral fertilizers and pesticides and energy embodied in buildings and machinery. Data for the Energy Input calculations came directly or indirectly from Statistics Canada publications and other energy reports. When data were lacking for certain years, values were estimated using known data. To ensure consistency with other studies, we did not include values for energy resource depletion (a factor that accounts for the extraction, refining and transportation of fossil fuels to the final user). Direct solar energy is also excluded from the calculations. Whenever possible, values for refined petroleum products and electricity were corrected to account for non-farm business usage.

The energy outputs were determined for 34 of the most abundantly produced commodities in Canada (see Table 10-1) by multiplying the amount of each commodity produced by an energy content coefficient. Production data were obtained from Statistics Canada databases, and the energy content coefficients from the US Department of Agriculture Nutrient Database. The amount of grain fed to livestock, along with pasture and hay, was excluded from the calculations to avoid double-counting (this energy content is embodied in livestock production).

The metric unit measure for energy used in the indicator is a petajoule, or PJ (1 PJ = 10^{15} joules). Note that 1 calorie is equal to 4.17 joules; 1 British Thermal Unit (BTU) equals 1,054.6 joules.

■ LIMITATIONS

The results for the Energy Use Efficiency Ratio presented here can be used, with appropriate caution, to identify trends in energy use efficiency in Canadian agriculture. However, the indicator cannot be considered a precise measure. This would require a complete understanding of the full life cycle of energy in relation to present and past technologies. As calculated, an increase in the output/input ratio may not necessarily mean that energy use efficiency has improved. This is because agricultural production (and thus energy input and output) is influenced by a variety of climatic and economic factors. For example, given a

Table 10-1: Agricultural commodities included in the Energy Output calculations

Apples
Barley
Beef
Blueberries
Canola
Carrot
Cauliflower
Chicken
Corn (for grain)
Corn (fresh)
Cucumbers
Durum
Eggs
Field peas
Flaxseed
Grapes
Lentils
Lettuce
Milk
Oats
Onions
Peaches
Pears
Peas
Pork
Potatoes
Raspberries
Rye
Soybeans
Spring wheat
Strawberries
Tomatoes
Turkey
Winter wheat

constant level of input, an increase in the energy ratio could simply be the result of better weather. Market prices may be responsible for shifts in livestock production, which in turn affect the quantities of wheat, barley, oats, canola, soybeans, corn and rye required to feed livestock, influencing energy output results. So while we can say that in general "higher is better," for the energy ratio, proper interpretation requires careful examination and understanding of the causes of changes.

Other limitations stem from the limited accuracy and availability of data. A combination of approaches is used to construct reasonable estimates and address these deficiencies, but better data would improve the accuracy of the indicator. It is also particularly difficult to make provincial or regional comparisons given the diversity of farm types, production practices and climates across Canada. For example, one region may seem to be energy inefficient (i.e. have a low output/input ratio) compared with other provinces but this may simply be because of a drier climate, resulting in lower yields, or because other provinces have a predominance of higher energy-containing crops such as oilseeds. For these reasons, it is more important to focus on trends rather than on energy values themselves.

■ RESULTS

Results for the two sub-indicators and for the Energy Use Efficiency Ratio are presented in Table 10-2 and Figures 10-1 and 10-2 and described below. For simplicity, and unless otherwise noted, the trends reported here refer to differences between the first (1981-1985) and last period (1997-2001) of this study.

Canada: At the national level, Energy Input increased by 16% (50 PJ) while Energy Output rose by 13% (78 PJ). The result was an overall decrease of 3% in the Energy Use Efficiency Ratio.

British Columbia: Energy Input increased by 37% (9 PJ) while Energy Output increased only 4% (0.4 PJ). The Energy Use Efficiency Ratio decreased by 24%.

Alberta: Energy Input increased by 8% (7 PJ) while Energy Output rose by 14% (21 PJ). The Energy Use Efficiency Ratio increased by 5%.

Saskatchewan: Energy Input increased by 30% (21 PJ) while Energy Output increased only 8% (20 PJ). The Energy Use Efficiency Ratio decreased by 19%.

Manitoba: Energy Input increased by 29% (10 PJ) while Energy Output increased only 13% (12 PJ). The Energy Use Efficiency Ratio decreased by 12%.

Ontario: Energy Input increased by 7% (5 PJ) and Energy Output rose by 20% (13 PJ). The Energy Use Efficiency Ratio increased by 11%.

Quebec: Energy Input increased by 9% (3 PJ) while Energy Output increased at a faster rate, namely 31% (9 PJ). The Energy Use Efficiency Ratio increased by 20%.

Atlantic: Energy Input decreased between 15% and 29% in the Atlantic Provinces, except Prince Edward Island, where it increased by 36%. Energy Output increased in all provinces, with the increases ranging from 7% to 46%. The Energy Use Efficiency Ratio increased in all the Atlantic Provinces: 37% for New Brunswick, 26% for Nova Scotia, 7% for Prince Edward Island and 93% for Newfoundland and Labrador.

INTERPRETATION

Canada: The fluctuations and overall decrease in the Energy Use Efficiency Ratio result from a proportionally greater increase in Energy Input than in Energy Output. On the input side, the largest contributor to the increase in Energy Input is diesel fuel (up by 78%), which was the largest input component (28%) of total energy use in the 1997-2001 period. The higher diesel usage is partly explained by its substitution for gasoline consumption (down 32%). This is part of the long-term trend toward more diesel powered engines in the sector. However, the explanation for this increase in fuel use is not clear-cut since there has been a marked increase in minimum and no-till practices, which are associated with reduced fuel use (Nagy et al., 2000). Another important contributing factor is the 16% increase in fertilizer (22% of total energy input). The bulk of this increase occurred in the 1980s, given that the increase between the periods 1989-1993 and 1997-2001 was only 2%. Pesticides rose by 64%, but account for only

Table 10-2: Energy use in agriculture, 1981 to 2001

Province	Energy Use Efficiency Ratio									Energy Use Trends								
	81 to 85			89 to 93			97 to 01			81-85 to 89-93			89-93 to 97-01			81-85 to 97-01		
	Input (PJ)	Output (PJ)	Ratio Out./In.	Input (PJ)	Output (PJ)	Ratio Out./In.	Input (PJ)	Output (PJ)	Ratio Out./In.	Input %	Output %	Ratio %	Input %	Output %	Ratio %	Input %	Output %	Ratio %
BC	24	8	0.3	26	8	0.3	33	8	0.2	10	1	-8	25	4	-17	37	4	-24
Prairies	192	513	2.7	203	589	2.9	231	567	2.5	6	15	8	13	-4	-15	20	11	-9
AB	89	153	1.7	85	180	2.1	96	174	1.8	-4	18	22	13	-3	-14	8	14	5
SK	70	268	3.9	78	307	3.9	91	289	3.2	12	14	1	16	-6	-19	30	8	-19
MB	34	92	2.7	40	102	2.5	44	104	2.4	18	11	-6	10	2	-7	29	13	-12
ON	65	63	1.0	63	66	1.0	69	75	1.1	-2	6	8	10	14	4	7	20	11
QC	31	28	0.9	31	30	1.0	34	36	1.1	0	7	6	8	22	14	9	31	20
Atlantic Prov.	8.9	8.9	0.9	7.2	10.0	1.2	8.5	11.3	1.2	-18	12	27	17	13	-1	-4	27	25
NB	3.5	3.2	0.9	2.4	3.3	1.4	2.9	3.7	1.3	-31	4	47	20	11	-7	-17	16	37
NS	2.6	1.7	0.7	2.0	1.8	0.9	2.2	1.8	0.8	-23	2	28	10	5	-2	-15	7	26
PEI	2.2	3.8	1.8	2.5	4.8	1.9	2.9	5.6	1.9	19	25	5	15	17	2	36	46	7
NL	0.6	0.1	0.3	0.2	0.1	0.6	0.4	0.2	0.6	-58	-2	90	68	48	1	-29	44	93
Canada	**310**	**620**	**2.0**	**319**	**703**	**2.2**	**360**	**698**	**1.9**	**3**	**13**	**10**	**13**	**-1**	**-12**	**16**	**13**	**-3**

Table 10-3: Relative distribution of Energy Input and Output values, 1997 to 2001

	Energy Input (in %)						Energy Output (in %)					
Province	Fossil Fuel	Electricity	Machinery	Building	Fertilizers	Pesticides	Wheat	Canola	Soybeans	Potatoes	Other crops	Animal
BC	29	4	56	7	3	<1	11	13	–	4	16	56
AB	45	4	20	6	23	2	39	28	–	1	25	7
SK	42	3	21	3	28	3	33	23	–	<1	41	2
MB	34	8	18	3	34	3	36	32	–	2	21	9
ON	47	8	19	12	12	2	19	1	34	2	17	27
QC	34	15	22	14	14	1	3	1	12	4	22	58
NB	40	8	23	10	17	3	4	–	–	59	10	27
NS	41	6	29	17	5	2	5	–	–	8	18	69
PEI	27	8	21	8	31	5	6	–	1	72	9	12
NL	59	11	19	9	1	1	–	–	–	6	2	92
Canada	**43**	**6**	**20**	**7**	**22**	**2**	**31**	**22**	**4**	**2**	**30**	**11**

2% of total energy input. On the output side, 23 of the 34 commodities saw their Energy Output values increase between the first and third periods. While a number of different factors are at play, a key contribution came from the increase in canola (up 169% or 96 PJ), which occurred largely at the expense of wheat (down by 31%, which represents the largest change in absolute terms, i.e. -98 PJ). The impact of these crops is important because they were the two most important components of energy output in the period 1997-2001 (wheat 31%, canola 22%) at the national level. Furthermore, canola (an oilseed) has a higher energy content than wheat. Other notable changes include the increase in energy output associated with field peas (30 PJ), which made up 5% of the total output; as well as an increase in livestock numbers (especially chickens and pigs), which somewhat offset the increase in crop energy output because of the higher feed consumption.

British Columbia: The decrease in the Energy Use Efficiency Ratio is mainly explained by a relatively large increase in Energy Input, mostly due to diesel fuel (73%) and machinery (43%), coupled with a more modest increase in Energy Output. The increase in output is largely attributable to increases in livestock production and livestock products (chicken 175%, milk 24% and beef 15%), which represented 46% of the total output energy during the period 1997-2001. Canola and oats also contributed to the increase in energy output (together they account for 18% of total energy output). These increases were counterbalanced by significant decreases in wheat (24%) and barley (72%).

Prairies: The decrease in the Energy Use Efficiency Ratio for the Prairie Provinces was due to an increase in Energy Input combined with a proportionally weaker increase in Energy Output, except in Alberta, where output increased more than input. In the Prairies, Energy Input and Energy Output made up 64% and 81% respectively of the corresponding total values for Canada during 1997-2001. The trends are quite similar to those for Canada as a whole, with the increase in energy input being mostly explained by increases in energy for diesel fuel (77%) and agricultural inputs (fertilizers 37% and pesticides 82%). The total Energy Output increase is attributable to increases in durum, oats, canola, lentils, field peas and pork. However, these increases were significantly offset by a 34% drop in wheat energy.

Ontario: The overall increase in the Energy Use Efficiency Ratio is explained by a comparatively larger increase in Energy Output compared to Energy Input between the two periods 1981-1985 and 1997-2001. Energy input for diesel fuel increased significantly (133%), but this was offset by a 40% decrease in fertilizer. The higher increase in output is explained by increases in three commodities: wheat (55%), soybeans (127%) and pork (19%). Together, they represented 63% of total energy output during the 1997-2001 period.

Quebec: Similar to Ontario, the increase in Energy Use Efficiency Ratio for Quebec is explained by a larger increase in Energy Output compared to Energy Input. The increase in energy input is mainly due to diesel fuel (35%) and buildings (36%), offset by a 50% decrease for gasoline. Pork (43%), chicken (78%), oats (203%), corn (18%), and soybeans (441% from 1989-93 to 1997-2001) were responsible for the Energy Output increase.

Atlantic: The changes in Energy Use Efficiency Ratio varied among the four Atlantic Provinces, but were always positive (overall increase of 25%). This is explained by a decrease in Energy Input combined with an increase for Energy Output, except in Prince Edward Island, where both increased. The major decrease in inputs was for gasoline (66%), while the Energy Output increases were mainly due to an increase for potato (34%) that represents 56% of total energy output. Wheat, oats and chicken also contributed to the total Energy Output increase.

Figure 10-1: Annual Energy Input and Energy Output in Canada

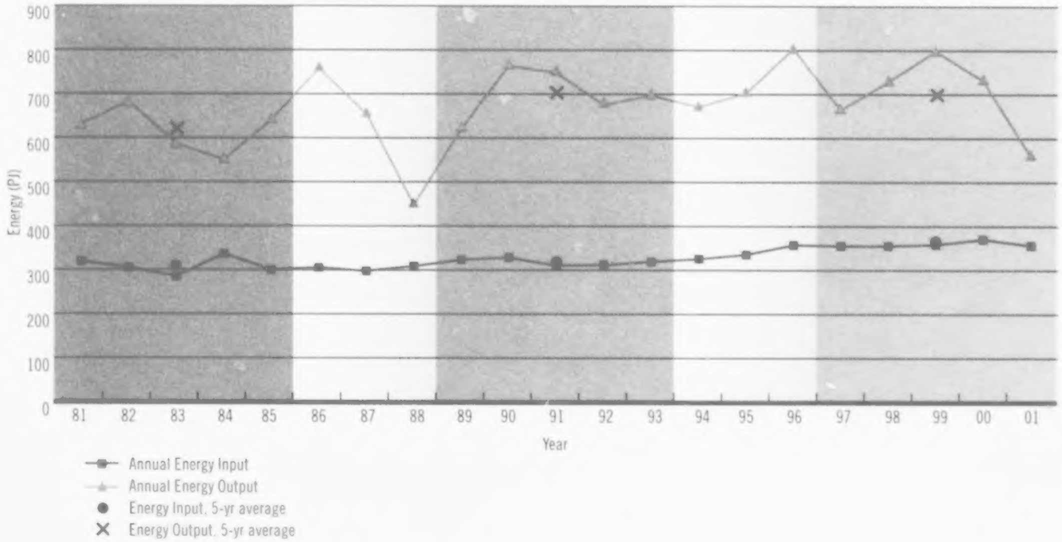
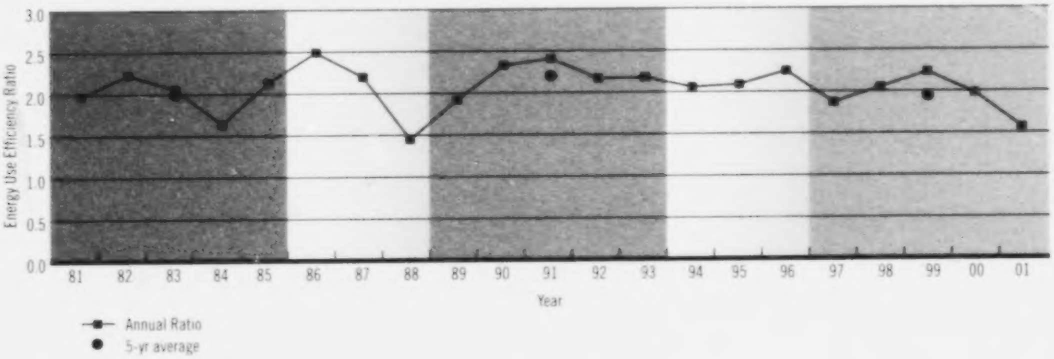


Figure 10-2: Annual Energy Use Efficiency Ratio in Canada



■ RESPONSE OPTIONS

There are several options available to Canadian farmers that could affect the Energy Use Efficiency Ratio for the sector. Various beneficial management practices (BMPs) can be adopted in seeking to minimize energy use without sacrificing economic productivity. One of the best examples of an emerging BMP is precision farming, a practice that involves applying an optimal quantity of inputs, such as fertilizer and pesticides, within fields or homogenous sections thereof. While still in the early stages of adoption because technical and cost issues are being ironed out, this technology holds promise of more efficient energy use. Other examples of BMPs include minimum-till or no-till practices, which can reduce fuel consumption, and the conversion of marginal (poor quality) land, typically requiring a large quantity of inputs, into more efficient land use. A combination of technical advances, economic incentives and Canadian farmer skill and creativity are prompting ever-greater adoption of beneficial practices such as these.

■ REFERENCES

Coxworth E., 1997. *Energy Use Trends in Canadian Agriculture: 1990 to 1996*, A report to the Canadian Agricultural Energy End-Use Data and Analysis Centre (CAEEDAC). University of Saskatchewan, Department of Agricultural Economics, Saskatoon (Sask.).

Nagy C.N., et al., 2000. *"Influence of Tillage Method on Nonrenewable Energy Use Efficiency in the Black and Grey Soil Zones"*. In Proceedings of the Climate Change Workshop: Saskatoon, Saskatchewan. Saskatchewan Agriculture, Food and Rural Revitalization, Regina (Sask.).

USDA Nutrient Database. www.nal.usda.gov/fnic

Weseen S., and R. Lindenbach, 1998. *Energy Use Efficiency Indicator for Agriculture*. University of Saskatchewan, Canadian Agricultural Energy End-Use Data and Analysis Centre (CAEEDAC), Saskatoon (Sask.).

11. Water Use Efficiency: Irrigation

AUTHORS:

L. Tollefson and
J. Harrington

INDICATOR NAME:

Water Use Efficiency Indicator for Irrigation

STATUS:

Currently under development

■ SUMMARY

The agriculture sector faces increasing competition from other water users for water resources. The greatest use of agricultural water is for irrigation. An indicator is currently being developed to quantify the use of freshwater resources for irrigation and to assess the efficiency of this practice. The Water Use Efficiency Indicator for Irrigation is comprised of three sub-indicators: Water Use Intensity, Water Use Technical Efficiency and Water Use Economic Efficiency. A method for calculating these indicators has been suggested using a pilot area approach as a starting point.

■ THE ISSUE

Irrigation or the artificial watering of the land may have both beneficial and harmful effects on the environment. Positive effects include groundwater recharge, regulation of run-off and flood control, re-use of water, protection against soil erosion and creation of wildlife habitat with increased biodiversity. Harmful effects may include soil *salinization* and water-logging, damage to river ecosystems from decreased flows, reduced water quality and pollution due to greater input use and transport of contaminants (Redaud 1998).

Irrigation is used in *semi-arid regions* of Canada such as the Prairie Provinces and, during dry years, in the more humid regions of central and Atlantic Canada, when water supplies are insufficient to meet crop requirements. The high cost of developing new water sources limits creation of new water supplies. This can potentially lead to trade-offs and even conflicts between agricultural production and other water uses. Where these constraints persist, the result may be reduced agricultural production, lower water supply for all users and a reduction in water quality (Wolff and Stein 1999).

A Water Use Efficiency Indicator for Irrigation is currently being developed to assess the use of freshwater resources for irrigation and the mass production and economic productivity of the water used for that purpose.

■ THE INDICATOR

A Water Use Efficiency Indicator for Irrigation is currently being developed to assess the use of freshwater resources for irrigation and the mass production and economic productivity of the water used for that purpose. This indicator encompasses three sub-indicators:

- Water Use Intensity (WUI): to measure annual abstraction (irrigation relative to renewable freshwater resources) and set the context for the other two sub-indicators;
- Water Use Technical Efficiency (WUTE): to assess the production efficiency of irrigation water used directly in crop production; and
- Water Use Economic Efficiency (WUEE): to assess the value of agricultural production per unit volume of irrigation water used directly for crops.

■ CALCULATION METHOD

During the initial testing phase of indicator development, the Water Use Intensity Indicator (WUI) will be calculated using the national estimates for irrigation water use and for freshwater resources compiled by Statistics Canada. The method used to estimate irrigation water use and *return flow* will be refined to provide accurate indicator values valid across Canada.

The Water Use Technical Efficiency (WUTE) sub-indicator will then be calculated as the mass of agricultural production of selected crops per unit volume of water extracted or diverted for irrigation, minus return flows. Three proxy crops will be used for estimating WUTE (potato, hard red spring wheat and alfalfa). They will provide a basis for national comparison and for comparison with rainfed yields if required.

The Water Use Economic Efficiency (WUEE) sub-indicator will be calculated as the value of crop production (all crops) per unit volume of irrigation water used.

The sub-indicators will be reported at a *watershed*, regional, provincial or national scale.

■ LIMITATIONS

At the heart of the water use indicators is the collection of reliable water data on a large scale. Existing water use data in Canada are often of poor quality and must be compiled from different sources. Some data are derived from primary estimates (measurements by the investigator) while other data will come from secondary sources (modelling, indirect estimates, etc.). Initially, gaps in the data will be overcome by making reasoned assumptions. As the indicators evolve, means of acquiring data through field measurements, weather-based models or remote sensing will be developed. Other challenges to indicator development lie in the scaling-up of information to the provincial and national levels, the uncertainties in regional water and crop estimates and the variability in price information.

■ RESULTS

This indicator is currently under development. Results are not yet available.

■ RESPONSE OPTIONS

In the long term, these sub-indicators will be sensitive to changes in farm-level management practices, such as agronomic advances (improved varieties, efficient input use), improved irrigation management (irrigation scheduling, system type), on-farm water management (mulches, avoiding high evapo-transpiration periods) and adoption of new technology (laser levelling, water saving systems). The indicators will also respond to regional (e.g. irrigation districts) changes in water management, such as improved infrastructure operation and maintenance, re-allocation of water to higher-value crops or uses, water pricing, improved management skills as a result of farmer training and advances in forecasting crop water requirements as well as water conservation methods.

■ REFERENCES

Burt, C.M., A.J. Clemmens, and K.H. Solomon, 1995. *"Identification and Quantification of Efficiency and Uniformity Components"*. Pages 1526-1530 in Proceedings of the ASCE Water Conference in San Antonio, Texas (*Water Resources Engineering*), ITRC Paper No. 95-005.

Redaud, J.L., 1998. *"Indicators to Measure the Impact of Agriculture on Water Use: Pricing and Cost of Water Services"*. In Proceedings of: The Sustainable Management of Water in Agriculture: Issues and Policies – The Athens Workshop. OECD, Paris (France).

Wells, C. and A. Barber, 1998. *Field Testing Indicators of Sustainable Irrigated Agriculture Study*. Policy Technical Paper 00/04, New Zealand Ministry of Agriculture and Forestry, Wellington (NZ).

12. Integrated Pest Management

AUTHORS:

G. Boivin,
J. Grimard
and C. Olivier

INDICATOR NAME:

Integrated Pest Management Adoption Index

STATUS:

Currently under development

■ SUMMARY

Producers are increasingly adopting integrated pest management *systems to reduce the use of chemical pesticides in agriculture while maintaining productivity. An indicator—the Integrated Pest Management Adoption Index—is currently being developed to assess the extent to which the main integrated pest management practices are being adopted. A survey approach will be employed to prepare a profile of crop pest control practices in Canada and to quantify the adoption of alternatives to chemical pesticides, for the main crops grown in Canada. The survey is to be repeated every five years.*

■ THE ISSUE

Currently, most crop pests are controlled through the application of chemical pesticides. The use of pesticides for crop protection has been linked to various disadvantages such as environmental pollution (air, soil, water), hazards for handlers and the periodic buildup of *pest resistance*. As part of their efforts to ensure more environmentally sustainable agriculture in Canada, producers are increasingly adopting alternative methods for managing pests. One such approach, called integrated pest management (IPM), is aimed at reducing chemical pesticide use in agriculture while maintaining productivity. IPM is a decision-making process that uses all necessary techniques to suppress pests effectively, economically and in an environmentally sound manner (ECIPM 2003).

■ THE INDICATOR

The proposed indicator—the Integrated Pest Management Adoption Index—is based on a scale from 1 to 5 (Table 12-1). A producer using only chemical treatments on a fixed schedule or according to crop growth stage is at Level 0 on this scale. As crop practices like pest scouting, economic thresholds (holding off with measures until economically damaging levels of pests are reached) and the use of pesticides that are less harmful to natural pest enemies are adopted, the producer then moves to Level 1. Producers who use alternative methods such as biological or physical control (e.g. mechanical destruction of pests), cultural practices, (e.g. crop rotation, use of resistant cultivars), biopesticides and predictive models are at Level 2 or 3. At Level 2 and higher levels, producers are considered to be employing an integrated pest management program. Producers at Level 4 consider the effects of their crop pest control practices on other

Table 12-1: Scale for the Integrated Pest Management Adoption Index

Level	Description
0	Chemical treatments applied on a regular basis or based on crop stages. Broad-spectrum pesticides used.
1	Chemical pesticide treatments. Use of pest scouting and economic thresholds. Selective pesticides used.
2	Pest control consists primarily of chemical pesticide treatments. Pest and *natural enemy scouting*. Use of action and inaction thresholds. Crop rotation. Selective pesticides used. Crop practices that reduce pest populations.
3	Pest control consists primarily of alternative methods. Use of models (based on accumulated *degree-days*) to predict the arrival of pests and natural enemies. Use of natural enemies (biological control). Use of resistant plants. Use of *biopesticides* (bioinsecticides, hormones, semiochemicals). When chemical pesticides are used, the producer uses selective pesticides that do not interfere with alternative methods.
4	Level 3 plus consideration of interactions among pest species. Habitat management. Use of expert systems. Dynamic pest/crop models.
5	Level 4 plus consideration of interactions among crops. Regional management.

Table 12-2: List of crops for which the Integrated Pest Management Adoption Index may be developed

- Alfalfa
- Apple
- Apricot
- Asparagus
- Bean
- Beet
- Blueberry
- Buckwheat
- Canola
- Carrot
- Celery
- Cherry
- Chick pea
- Corn
- Cranberry
- Dry beans
- Field cucumber
- Field tomato
- Ginseng
- Grape
- Green pea
- Greenhouse cucumber
- Greenhouse tomato
- Hop
- Leek
- Lentil
- Melon
- Mushroom
- Mustard
- Oat
- Onion
- Peach
- Pear
- Plum
- Potato
- Radish
- Raspberry
- Rye
- Soy
- Spinach
- Strawberry
- Sunflower
- Sweet pepper
- Wheat

crop pests at the field level. Finally, producers at Level 5 manage pests not just within a single crop, but at the farm or regional level, and they base their decisions regarding crop rotations and companion crops on the associated effects on pests, for all crops on their farms.

IPM is a decision-making process that uses all necessary techniques to suppress pests effectively, economically and in an environmentally sound manner (ECIPM 2003).

CALCULATION METHOD

As currently proposed, the Integrated Pest Management Adoption Index will be calculated by using crop-specific questionnaires to survey a representative sample of producers. The surveys will be conducted at regular intervals (e.g. every five years) so as to eventually cover all 48 of Canada's primary grain, vegetable and fruit crops (based on surface area and value) (Table 12-2). The survey questionnaires will comprise all the IPM techniques available to producers, for each individual crop. Points will be awarded for each integrated pest management practice that a producer uses (details of the scoring system are currently being developed). A producer's accumulated points will provide a total, which will be converted into an index using an integrated pest management adoption scale (Table 12-1) similar to those used in other countries (Benbrook et al. 1996, Frantz and Mellinger 1998, Kogan 1998). The value obtained will be adjusted based on crop-specific characteristics. These calculations will yield average adoption rates for integrated pest management practices, by crop and by province.

LIMITATIONS

Various factors may influence the accuracy of the results for the Integrated Pest Management Adoption Index, such as errors in identifying the available integrated pest management practices for each crop, the accuracy and quality of the answers on the questionnaires and the distribution and number of respondents covered across Canada. To ensure that the survey samples are representative, the statistical analyses are sound and confidentiality is maintained, the survey is to be prepared in co-operation with Statistics Canada.

RESULTS

This indicator is currently under development and results are not yet available.

RESPONSE OPTIONS

When fully developed, this indicator will assess changes in the adoption of IPM systems by producers. An increase in the level of adoption of integrated pest management over the years would show that producers are successfully adopting alternatives to chemical pesticides. If the adoption level is considered to be unsatisfactory, the underlying information will aid in determining whether the low adoption level is connected with a lack of viable alternative methods (necessitating research efforts), limited availability (requiring marketing) or insufficient information for producers (necessitating extension). The survey approach may make producers aware of the alternative pest management methods that are available for their crops and may encourage them to adopt such measures.

REFERENCES

Benbrook, C.M., E. Groth III, J.M. Halloren, M.K. Hansen, and S. Marquardt, 1966. *Pest Management at the Crossroads*. Consumers Union, Yonkers (N.Y.).

ECIPM (Expert Committee on Integrated Pest Management), 2003. *Resources on IPM (Web site)*. www.carc-crac.ca/english/ECIPM/ ecipm.htm

Frantz, G. and H.C. Mellinger, 1998. "*Measuring Integrated Pest Management Adoption in South Florida Vegetable Crops*". Paper No. 132, Proceedings of the Annual Meeting of the Florida State Horticultural Society, Vol. 111, pp. 1-15.

Soil Quality

C

13. Soil Erosion

■ SUMMARY

Soil erosion, the movement of soil from one area to another, occurs through three main processes. It occurs naturally on cropland through the action of wind and water, which can be accelerated by some farming activities (e.g. summerfallow, row cropping). It is also caused directly by the farming practice of tillage, which causes the progressive downslope movement of soil, resulting in soil loss from hilltops and soil accumulation at the base of hills. Soil erosion is a major threat to the sustainability of agriculture in Canada. It removes topsoil, reduces soil organic matter and contributes to the breakdown of soil structure. These effects in turn adversely affect soil fertility, the movement of water into and from the soil surface and ultimately crop yields and profitability. Yields from severely eroded soils may be substantially lower than those from stable soil in the same field. Erosion can also have significant "off-site" adverse impacts on the environment through the physical transport and deposition of soil particles and through the nutrients, pesticides, pathogens and toxins that are released by erosive processes or carried by eroded sediments. This chapter deals with three distinct indicators that are used to assess the risk of soil erosion by the action of water, wind and tillage.

A) Water Erosion

AUTHORS:
L.J.P van Vliet,
G.A. Padbury,
H.W. Rees and
M.A. Matin

INDICATOR NAME:
Risk of Water Erosion

STATUS:
National coverage, 1981 to 2001

■ SUMMARY

Soil erosion by water has long been recognized as a serious threat to agricultural sustainability in Canada, albeit to a lesser extent on the Prairies. Results from the Risk of Water Erosion Indicator point to an overall decrease in water erosion risk in most provinces of Canada, between 1981 and 2001, contributing to a national decrease of 8%. This positive trend resulted mostly from changes in cropping measures and the increased use of conservation tillage and no-till. In 2001, 86% of cropland in Canada exhibited sustainable levels of erosion (very low risk class). The remaining 14% of Canadian cropland, which is still subject to unsustainable water erosion, typically consists of areas used for summerfallow and row cropping on sloping land.

■ THE ISSUE

Rainfall and surface run-off are the driving forces for water-induced soil erosion. Spring meltwaters and heavy summer storms have the greatest potential for causing water erosion; however, water erosion can occur any time, contributing to large soil losses from farm fields over time and soil degradation. Eroded soil is carried in run-off to agricultural drains, ditches and other waterways, where it can affect water quality, given that suspended soil particles increase the turbidity (cloudiness) of the water and add to sediment build-up. This sedimentation may reduce the water's suitability as habitat for fish and other aquatic organisms, alter the flow of the water and eventually clog channels, making clean-up necessary. In addition, crop nutrients, pesticides and bacteria are often attached to the eroding soil particles and so are also carried into water bodies, adding to the water quality impacts. Curtailing water erosion can help to protect both soil and water quality.

THE INDICATOR

The Risk of Water Erosion Indicator is used to identify areas at risk of significant water erosion and to assess how this risk is changing over time under prevailing management practices. This risk is expressed in five classes: very low (less than 6 tonnes per hectare per year), low (6 to 11 t ha^{-1} yr^{-1}), moderate (11 to 22 t ha^{-1} yr^{-1}), high (22 to 33 t ha^{-1} yr^{-1}) and very high (greater than 33 t ha^{-1} yr^{-1}). Areas in the very low risk class are considered, under current conditions, able to sustain long-term crop production and maintain agri-environmental health. The other four classes represent the risk of unsustainable conditions that call for soil conservation practices to support crop production over the long term as well as to reduce impacts on water quality. The performance objective for this indicator is to increase the proportion of cropland in the very low risk class.

> *In 2001, 86% of Canadian cropland was in the very low water erosion risk class.*

CALCULATION METHOD

The rate of water erosion was estimated using the Revised Universal Soil Loss Equation for Application in Canada (Wall et al. 2002). The Soil Landscapes of Canada (SLC) maps (version 3.0) and its attribute files provided information on the location of soils in the landscape and corresponding slope gradient (steepness) and length, along with soil properties for each mapping area. Data for soil properties, extracted from the SLC soil layer files, were used to calculate the inherent *erodibility* of each soil (K value). Values for the rainfall-run-off factor (R) were tabulated from existing data sources for each SLC mapping area.

The change in rate of water erosion over time was calculated by considering the effects of changes in land use and tillage practices across Canada, such as fluctuations in cropland areas, shifts in the types of crops grown and the use of conservation tillage and no-till. This information was obtained from the Census of Agriculture for 1981, 1986, 1991, 1996 and 2001, and also linked to each SLC mapping area. The proportion of cropland falling into each of the risk classes outlined above was calculated for Canada and for each province. Changes over time in the percent value for each class in each area provides an indication of whether the overall risk of erosion is increasing or decreasing.

LIMITATIONS

The indicator is subject to the following limitations:

- calculations did not account for some erosion control practices such as *grassed waterways, strip cropping, terracing, contour cultivation* and winter cover crops.
- Census data linked to mapping areas were assumed to be equally distributed over the entire mapping area, because crop types and tillage practices could not be directly linked to specific soil types or landscape features within each SLC mapping area.
- Census information is not detailed enough to reflect the geographic distribution of management practices in landscapes where farmland is fragmented.
- slope lengths were determined for each landform, and did not account for interception of run-off by roadways, field boundaries, ditches, ponds and drainage ways.
- the indicator is based on long-term average annual rainfall data that may not reflect single high intensity rainfall events that can cause significant soil erosion.

RESULTS

The risk of water erosion in Canada and in each province is shown for 1981, 1986, 1991, 1996 and 2001 in Table 13-1. Figure 13-1 shows the distribution of the various risk classes in Western and Eastern Canada in 2001.

Canada: In 2001, 86% of Canadian cropland was in the very low (tolerable) water erosion risk class, up by 8% from the 1981 level. Hence,

Table 13-1: Share of cropland in various water erosion risk classes, 1981 to 2001

Share of Cropland in Different Water Erosion Risk Classes (in %)

Province	Very Low					Low					Moderate					High					Very High				
	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01
BC	63	65	71	72	75	19	17	17	15	15	11	10	6	6	5	1	1	1	5	4	6	7	5	1	<1
AB	80	81	83	87	90	11	11	9	6	4	4	3	3	3	4	2	2	3	3	1	3	3	2	1	1
SK	85	88	89	90	92	7	5	5	4	4	4	3	3	3	3	2	2	2	2	2	2	2	2	1	1
MB	83	86	87	91	95	13	10	10	7	4	3	2	2	1	<1	<1	<1	<1	<1	<1	2	1	1	1	1
ON	44	45	45	56	56	22	23	23	15	15	15	16	14	16	16	11	9	10	6	7	8	8	7	7	6
QC	70	73	73	72	71	14	12	12	13	15	7	6	6	7	6	4	6	6	5	4	5	3	3	3	4
NB	54	54	55	54	55	18	20	19	20	21	24	23	24	23	21	4	3	2	3	3	<1	<1	<1	<1	<1
NS	61	64	65	64	65	21	22	24	23	23	13	10	8	9	10	4	4	2	2	1	1	1	1	2	1
PEI	52	51	52	50	51	38	38	37	39	39	3	4	4	4	3	5	5	5	5	5	2	2	2	2	2
Canada	**78**	**80**	**82**	**84**	**86**	**11**	**9**	**9**	**7**	**6**	**5**	**5**	**4**	**4**	**4**	**3**	**3**	**3**	**3**	**2**	**3**	**3**	**2**	**2**	**2**

* In Newfoundland and Labrador, the proportion of agricultural polygons was not sufficient to provide reliable results. Therefore, results for NL were not reported.

an overall decrease of 8% was recorded in the water erosion risk for Canada during the 20-year period under review, from a 1% decrease in cropland area in each of the moderate, high and very high risk classes and a 5% decrease in cropland area in the low risk class.

British Columbia: This province (like Alberta, Manitoba and Ontario) posted the largest decrease in water erosion risk, with 12% of cropland moving into the very low risk class, which comprised 75% of the land in 2001. This shift occurred mainly through reductions in the low, moderate and very high risk classes.

Prairies: Manitoba, Alberta and Saskatchewan showed improvements in water erosion risk of 1% to 4% between each Census year. This translated into an overall gain of 12%, 10% and 7% of cropland respectively in the very low risk class between 1981 and 2001. In 2001, all three Prairie Provinces had 90% or more of their cropland in the very low risk class (AB: 90%; SK: 92%; and MB: 95%).

Ontario: An overall reduction of 12% was recorded in the risk of water erosion between 1981 and 2001, with most of this improvement (11%) occurring between 1991 and 1996 through an 7% shift of cropland from the low risk class and a 4% shift of cropland from the high erosion class. However, despite this improvement, Ontario had one of the lowest proportions (56%) of cropland in the very low risk class and the largest share (6%–8%) of cropland in very high risk class during the 20-year period.

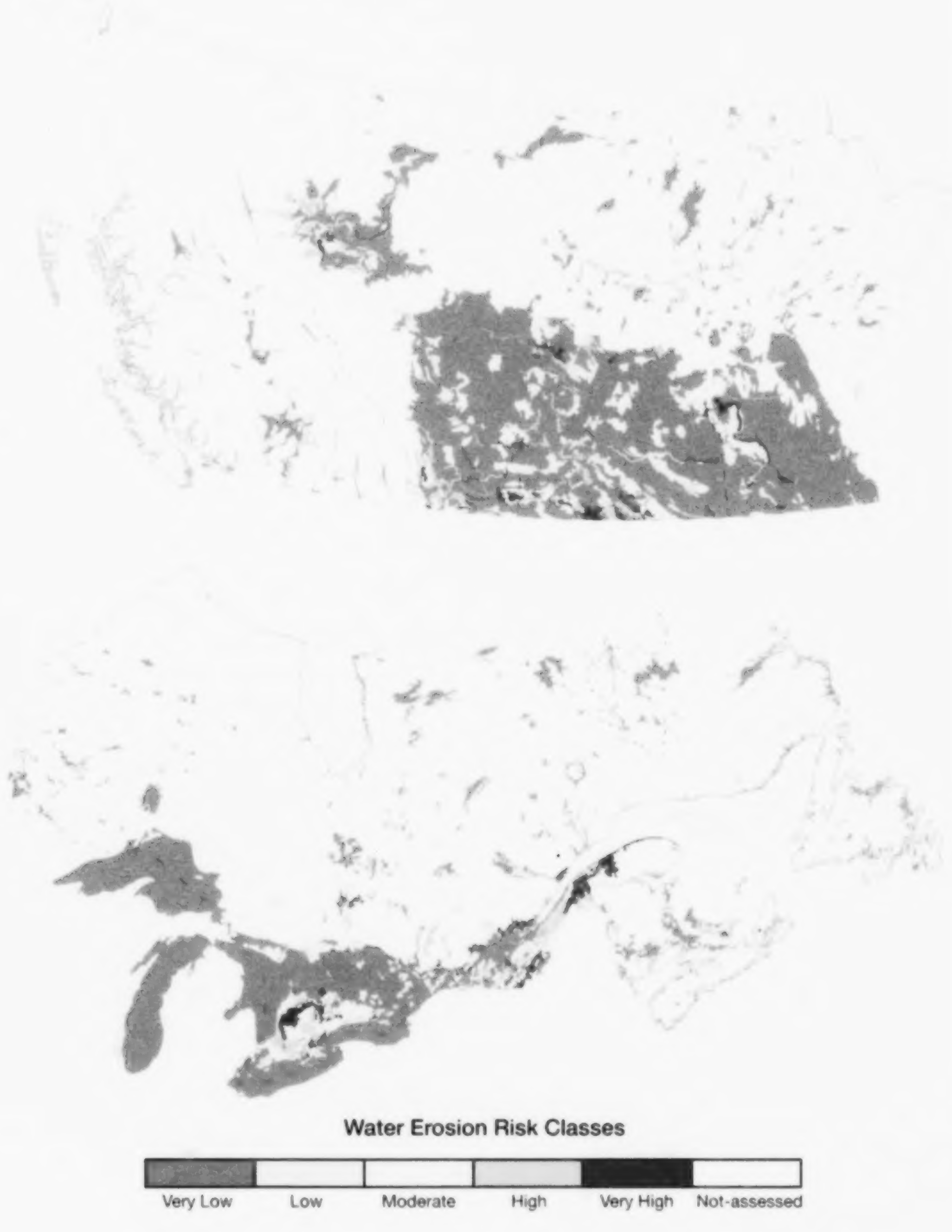
Quebec: Only slight changes were observed in the various risk classes over the 20-year period. The share of cropland in the very low risk class increased slightly between 1981 and 2001, from 70% to 71%. Between 3% and 5% of cropland was in the very high erosion risk class during each of the five Census years.

New Brunswick: The risk of water erosion decreased 1% between 1981 and 2001, with only slight changes between Census years. There was a 3% shift in cropland area from the moderate to the low erosion risk class.

Nova Scotia: The share of cropland in the very low risk class fluctuated between 1981 and 2001, showing an overall 4% increase (to 65%). There was a 3% reduction in cropland area in the moderate and high risk classes.

Prince Edward Island: This province had the lowest share (51%) of cropland in the very low erosion risk class in 2001 showing a 1% increase in water erosion risk between 1981 and 2001. However, there was a 1% decrease in water erosion risk between 1996 and 2001. Prince Edward Island has the highest proportion of cropland (one-third) in the low erosion risk class.

Figure 13-1: Risk of Water Erosion on cultivated land in Canada under 2001 management parctices


Water Erosion Risk Classes
Very Low
Low
Moderate
High
Very High
Not-assessed

Newfoundland and Labrador: Only a few agricultural map areas were included in the analysis for Newfoundland and Labrador. A shift in class by one or two map areas resulted in a dramatic change in the share of cropland in the different risk classes. Consequently, the results were not reliable and could not be used in the same way as for the other provinces, each with several hundreds of map areas. Therefore, results for Newfoundland and Labrador are not reported.

■ INTERPRETATION

In the following national and provincial descriptions, changes in erosion risk are stated for the period 1981 to 2001.

Canada: The general trend of decreasing water erosion risk between 1981 and 2001 in Canada reflects the degree to which changes have been made in cropping systems and tillage practices. Despite a net increase of nearly 0.4 million hectares in cropland area, a combination of reduced tillage, less-intensive crop production, decreased summerfallow and removal of marginal land from production all contributed to lower erosion rates. Substantial progress has been made in the adoption of no-till and conservation tillage since 1981, to the extent that in 2001, 58% of Canadian cropland is tilled in a conventional way compared with approximately 100% in 1981. The area in summerfallow has also decreased dramatically by just over half.

> *A combination of reduced tillage, less-intensive crop production, decreased summerfallow and removal of marginal land from production all contributed to lower erosion rates.*

British Columbia: A combination of reduced tillage, less-intensive crop production and decreased summerfallow all contributed to the decline in the risk of water erosion. A large increase in cropland area used for alfalfa production and the substantial decrease in summerfallow, mainly in the Central Interior and Peace River regions, more than offset the higher risk of erosion caused by the intensification of farming in the South Coastal region. Conservation tillage and no-till were practised on about 35% of British Columbia's cropland in 2001.

Prairies: In the Prairies, which account for 85% of Canada's cropland area, the risk of water erosion, already quite low, dropped by between 7% and 12%, because of the growing use of conservation tillage and no-till, the reduced summerfallow area and shifts in the type of crops grown, while total cropland area remained fairly constant. The improvement in erosion risk was particularly marked in regions of less-intensive agriculture, such as the Eastern Continental Ranges (foothills area) and the Western Alberta Uplands (Grey-Wooded soil zone). Nationally, the Prairie Provinces posted the largest gains in reduced-tillage use. Areas remaining in the high and very high risk classes tend to be characterized by erosion-prone soils and steeper landscapes; they would benefit from greater adoption of conservation practices. In Manitoba, the drop in erosion risk is attributed to a 50% drop in summerfallow and an associated expansion in continuous cropping as well as to the recent trend of enhanced crop diversification. This trend has resulted in more land being used to produce annual crops, as well as longer rotations because of the inclusion of new crops.

Ontario: This province had one of the smallest proportions of cropland in the very low water erosion risk class and 6% of cropland in the very high risk class, in 2001. Although the overall risk of erosion dropped substantially (12%), just under half of cropland remained in the unsustainable risk classes (low risk and higher) in 2001, principally owing to the large area in row crops. Of all provinces in Canada, Ontario has the highest proportion (over half) of its cropland in row crops, such as corn, soybeans and vegetables. Of all crops, row crops have the largest proportion of bare soil and the least amount of crop canopy, which spells poor protection of soil from raindrop impact and run-off erosion. Ontario's improved water erosion risk is mainly attributable to the high reduced-tillage adoption rate, which has had a positive effect on the large areas planted to corn and soybeans because of the residues retained.

Quebec: Major shifts in cropland area occurred between alfalfa, tame hay and fodder crops and row crops, such as grain corn, soybeans, vegetables and berries, which provide much less erosion protection. However, the reduced-tillage adoption rate of 20% has generally offset the shift to intensified row crop production. Despite variable cropland area over the five Census years and some shifts in other crops, only small improvements have occurred in the risk of water erosion. Still, Quebec has a low overall risk compared to other eastern provinces, mainly because of its gently rolling agricultural landscapes and less erosive soils.

Atlantic: Of all the provinces, Prince Edward Island and New Brunswick had the lowest share of cropland at very low risk of water erosion in 2001. Both provinces have a significant proportion of cropland in row crops, mostly in potatoes (65,000 ha in total). Potatoes are very erosion-prone, because the exposed soil and limited canopy cover provide little protection against water erosion. Also, decades of continuous potato production have reduced the organic matter content in the surface soil by half, making the soils more erodible. Soil erodibility associated with spring cereals planted after potatoes is greater than that associated with spring cereals planted after a forage crop.

New Brunswick's rolling, moderately long slopes and intensive cropping are conducive to water erosion. The high risk lands consist primarily of those under potato production in the northwest of the province. New Brunswick has a relatively low share of cropland in the very low risk class, but less than 1% of its cropland is in the very high erosion risk class.

The drop in erosion risk for Nova Scotia between 1981 and 2001 points to the successful adoption of conservation tillage and, to a lesser extent, the growing of crops, such as hay and cereal grains, that are less erosion-prone than row crops. Nova Scotia tends to receive more precipitation than the other Atlantic Provinces and it has a greater potential for erosion by rainfall, snowmelt and winter run-off. It has a much smaller area of potato production than New Brunswick or Prince Edward Island, but larger areas under vegetables and berries. The erosive effects of the greater cropland area in berries, grain corn and vegetables in 2001 were offset by increases in tame hay area and in conservation tillage, bringing a small improvement in erosion risk.

Prince Edward Island, the only province with an increase in erosion risk (1%), had less than half of its cropland in the very low risk class, and 7% of cropland was still in the high and very high erosion risk classes between 1981 and 2001. Fine sandy loam soils that erode easily are the most common. The area of erosion-prone row crops, particularly potatoes, increased significantly between 1991 and 1996, causing an increase in erosion risk of 2%. However, intensification in cropping was partially offset by increases in the use of conservation tillage, tame hay and crop rotations. Adoption of no-till remains very limited.

■ RESPONSE OPTIONS

Management practices that aid in controlling erosion include the following: using conservation tillage and managing crop residues; including forages in rotations; planting row crops across the slope or following the land's contours; strip cropping; growing cover crops; *interseeding* row crops with other crops, such as red clover; winter cover cropping where soils are at risk of erosion by winter run-off. More research needs to be done on alternatives to no-till for areas where this practice is not viable, such as areas of intensive horticultural or potato production. Where water erosion is very high, conservation tillage and cropping systems might be inadequate to control erosion and run-off. Erosion control structures, often more costly and labour-intensive than management practices, might be needed. These include terraces, or steps, to reduce slope steepness and length; permanent small earth berms or diversions running along the contours; and grassed waterways, which trap sediment moving off the field.

Considering the potential amount of soil loss—calculated by multiplying the share of cropland in each erosion risk class by the erosion rate for the class, we can estimate that 16% of the total annual soil loss occurs in the very high risk class, hence affecting less than 2% of Canada's total cropland area. Targeting agronomic and engineering practices to erosion-prone sites in such areas would help to significantly reduce water erosion in Canada. Soil landscapes in Ontario, Prince Edward Island, New Brunswick and Nova Scotia should be the primary focus of remedial measures, because these areas have the greatest share of cropland in the unsustainable erosion classes. Furthermore, they are generally the areas most prone to erosion because of precipitation patterns, intensive row cropping and crop production on unsuitable slope positions.

Erodible landscapes are often localized and relatively small but they can be major sites of soil loss. These areas are sometimes overlooked in broad-scale conservation programs and they should be targeted through practices, programs and policies tailored to their needs. Such a targeted approach is of crucial importance in the following regions: intensively cropped areas in Ontario, particularly those in the very high erosion class; potato growing areas on Prince Edward Island, the potato belt of northwestern New Brunswick; and broad areas of Nova Scotia used to grow potatoes, vegetables, grain corn and berries.

■ REFERENCES

Wall, G.J., D.R. Coote, E.A. Pringle, and I.J. Shelton (eds), 2002. *RUSLEFAC – Revised Universal Soil Loss Equation for Application in Canada: A Handbook for Estimating Soil Loss From Water Erosion in Canada*. Agriculture and Agri-Food Canada, Ottawa (Ont.). http://res2.agr.ca/ecorc/pubs/pdf/rusle_e.pdf

B) Wind Erosion

■ SUMMARY

Soil erosion by wind has long been a concern in many areas of Canada, especially in the semi-arid Prairies where the climate is dry and large tracts of cultivated land lie unprotected from the wind. Results from the Risk of Wind Erosion Indicator reveal that from 1981 to 2001 the risk of wind erosion in the Prairie region declined by about 40%, to the point where over 90% of the arable land *is now in the very low to low wind erosion risk classes, and only 3% is in the high to very high risk classes. This decline is attributable to higher residue levels resulting from a 50% decrease in the amount of summerfallow, a doubling of forage area and a significant increase in reduced-tillage practices.*

AUTHORS:
H. Rostad and
G. Padbury

INDICATOR NAME:
Risk of
Wind Erosion

STATUS:
Provincial
coverage
(BC, AB, SK, MB),
1981 to 2001

■ THE ISSUE

While wind erosion is a concern in many areas of Canada—from the *sandy soils* along the Fraser River in British Columbia to the coastal areas of the Atlantic Provinces—it is in the Prairie Region that the potential for wind erosion is by far the greatest. This situation stems from the region's dry climate and vast expanses of cultivated land with little protection from the wind. Since the Dust Bowl of the 1930s, the risk of wind erosion has been significantly reduced through improved land management, most notably the conversion of the more susceptible lands to perennial forages and more recently the trend toward less summerfallow and reduced-tillage. Whereas during the 1930s and the 1940s, intensive tillage with disc-type implements was required to prepare the seedbed, today's seeding equipment can seed and apply fertilizer in one pass, even with high residues.

■ THE INDICATOR

The Risk of Wind Erosion Indicator (RWndE) is used to assess how the risk of soil degradation from wind erosion on cultivated agricultural lands is changing relative to changes in farming practices. The risk is expressed in five relative classes: very low, low, moderate, high and very high. The indicator is applied to the agricultural regions of Manitoba, Saskatchewan and Alberta, as well as to the Peace River area of British Columbia, where this issue is of prime concern. Wind erosion can and does occur in other parts of Canada, and procedures are being developed to apply the RWndE Indicator there as well. The performance objective is to have all agricultural lands in the low or very low risk class.

■ CALCULATION METHOD

The rate of wind erosion was estimated using the Wind Erosion Equation (WEQ), (Woodruff and Siddoway 1965). The model utilizes a climatic factor based on wind speed and rainfall, along with soil factors largely related to soil texture. Superimposed on the soil and climate factors is a vegetation factor based on crop residue levels. Crop and tillage information from the Census of Agriculture findings for 1981, 1986, 1991,1996 and 2001, linked to Soil Landscape of Canada polygons, was used to provide an estimate of change in land use and management on different soil types.

Conceptually, the estimation of wind erosion risk involves first calculating the risk on bare, unprotected soil and then reducing that risk according to the amount of crop residues left on the soil surface and their effectiveness in controlling erosion. The risk of wind erosion was calculated for the April–May period after seeding, when residue levels are lowest and wind speeds are highest. Estimates of residue levels for different crops under different tillage regimes were derived from the Agriculture Canada research of McConkey et al. (2000) and from the study by Moulin and Beimuts (2000). More specifically, initial post-harvest residues for each crop in a particular region were estimated using average yields and a harvest index; they were then reduced according to the number and type of tillage operations associated with the conventional tillage, conservation tillage and no-till regimes in each region. Since tillage information was not compiled in the Census prior to 1991, for 1981 it was assumed that all tillage was conventional and for 1986 it was assumed that tillage levels were mid-way between those of 1981 and 1991.

■ LIMITATIONS

In order to accurately assess the wind erosion risk for a particular area, a link must be established between the type of crop, the soil type on which it is grown and the tillage practices used. However, SLC polygons typically contain several soil types along with numerous crops and tillage regimes, and it is not possible to determine which crops are being grown on which soil types, or which tillage practices are associated with specific crops or soil types. The best approach is to allocate soil types and tillage regimes proportionally among the various crops within each polygon. This, however, overlooks the fact that farmers often tailor their choice of crops and tillage practices to specific soil conditions, especially if the inherent risk of wind erosion is high. For example, rarely would a farmer practice summerfallow, plant low-residue canola or pulse crops, or use conventional tillage on a highly erodible sandy soil, but such scenarios are the inevitable result of proportional allocation and most likely cause an overestimation of the wind erosion risk. Another problem with the procedure is that because the yield estimates, climatic parameters and tillage regime information (e.g. type of implement and number of tillage operations) are based on average values, the system is insensitive to instances of excessive tillage or to extended periods of drought, which can generate below-average residue levels and higher wind erosion risk compared to what the model predicts.

Overall, from 1981 to 2001 there was about a 40% decrease in the wind erosion risk.

■ RESULTS

Estimates of the risk of wind erosion in the Prairie region of Western Canada and for each province for 1981, 1986, 1991, 1996 and 2001 are shown in Table 13-2. Figure 13-2 shows the distribution of wind erosion risk classes across the region in 2001.

Overall, from 1981 to 2001 there was about a 40% decrease in the wind erosion risk, with the proportion of land in the low to very low risk classes increasing from 84% in 1981 to 92% in 2001. The share of cultivated farmland at moderate to very high risk of wind erosion decreased by almost half, from 15% in 1981 to 8% in 2001.

In **British Columbia** the risk of wind erosion is low, with 99% of the improved agricultural land being in the low to very low classes in 2001, up 2% from 1981.

Alberta also has a low and declining wind erosion risk, with the amount of land in the low to very low risk classes increasing from 97% in 1981 to 99% in 2001. The 1% to 2% of area in the high and very high risk classes consists of sandy loam and *loamy sand soils*, with moderate risk soils (2%) being mainly clays under conventional tillage.

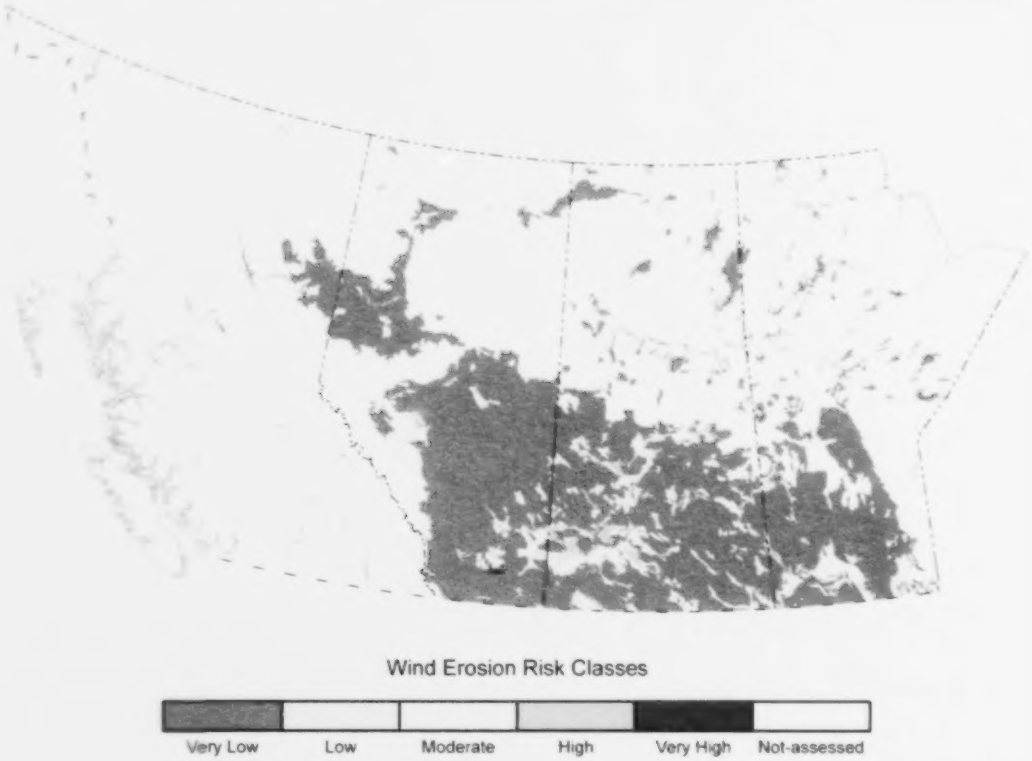
Saskatchewan has a significantly higher wind erosion risk than Alberta, but the trend has steadily improved, from 79% in the low and very low risk classes in 1981 to 88% in 2001.

Table 13-2: Share of cultivated land in various wind erosion risk classes, 1981 to 2001

Share of Cropland in Different Wind Erosion Risk Classes (in %)

	Very Low					Low					Moderate					High					Very High				
Province	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**
BC	94	94	95	97	97	3	3	3	2	2	1	1	1	1	1	2	2	1	1	1	<1	<1	<1	<1	<1
AB	86	87	90	91	94	7	6	5	4	2	5	4	3	3	2	1	1	1	1	<1	2	2	2	1	1
SK	62	69	74	78	81	17	13	11	9	7	13	11	8	8	7	3	3	2	2	2	5	5	4	4	3
MB	75	76	81	81	82	10	10	8	8	7	8	8	6	6	6	3	2	2	2	2	4	5	3	3	3
Prairies	**72**	**76**	**80**	**83**	**86**	**12**	**10**	**8**	**7**	**6**	**9**	**8**	**6**	**6**	**5**	**2**	**2**	**2**	**2**	**1**	**4**	**4**	**3**	**3**	**2**

Figure 13-2: Risk of Wind Erosion on cultivated land in the Prairie Region under 2001 management practices



Manitoba has also shown a significant reduction in wind erosion risk, with the proportion of land in the low and very low risk classes going from 85% in 1981 to 89% in 2001.

■ INTERPRETATION

The risk of wind erosion in the Prairies declined steadily between 1981 and 2001, because of changes in cropping systems and tillage practices. The most notable changes include a 50% reduction in the amount of summerfallow, a doubling of forage area and a dramatic increase in reduced-tillage systems to the point where nearly one hectare in three is now direct-seeded. Most of the observed reduction in risk can be attributed to this change in tillage practices. While there has been a significant trend toward more forage and less fallow, the beneficial effect on wind erosion has largely been offset by an increase in low-residue canola and pulse crops at the expense of cereals, particularly over the past 10 years or so. Furthermore, some 3.4 million hectares are still at moderate to very high risk of wind erosion. And while this represents less than 10% of the arable land in the Prairies, it exceeds the total amount of arable land in Canada east of Ontario.

British Columbia: In the Peace River area, the risk of wind erosion is low, primarily because of the relatively cool, moist climate there. The increase in the proportion of land rated in the low to very low risk classes reflects a 12% increase in direct-seeding, a 27% decrease in summerfallow and a corresponding increase in forage production.

Alberta: This province likewise has a low wind erosion risk, attributable in part to the cool, moist climate of the Peace River area and other northern regions. However, the risk level is low even in the arid southern regions because most (80%) of the cultivated soils there are loamy textured and thus relatively resistant to wind erosion, and because many of the susceptible soil types have been planted to forage. About 20% of cultivated land in the Brown and *Dark Brown soil* zones of Alberta is used for forage, while in similar regions of neighbouring Saskatchewan, the corresponding proportion is less than 10%.

Saskatchewan: The wind erosion risk is higher here than in Alberta mainly because of the higher proportion of cultivated land in the more arid Brown and Dark Brown soil zones and the slightly higher proportion of erosion-prone sandy and clayey soils. Nonetheless, the trend has improved, owing to a 50% reduction in the area of summerfallow and a dramatic increase in the use of direct-seeding technologies, to the point where nearly 40% of the area seeded each year is a one-pass operation.

Manitoba: This province has also seen a significant decline in the wind erosion risk, and although it has a significantly wetter climate than Saskatchewan, with proportionally less fallow and more forage, the erosion risk is comparable owing to the higher proportion of cultivated sandy (22%) and clayey (23%) soils.

■ RESPONSE OPTIONS

Approximately 20% of the area at moderate to very high risk in the Prairies is comprised of loamy sand soils, where planting perennial forages is the most practical response option. In the northern areas, though, the risk can be diminished sufficiently using a strict no-till regime. For sandy loam soils, which account for about a third of those at risk, summerfallow should be avoided, although *chem-fallow* can be used in the Black and Gray soil zones. Direct-seeding is the best option when planting into pulse or canola residues. The remaining area at risk is comprised of loamy or clayey soils that are either under conventional fallow or planted into pulse or canola residues using conventional tillage. It is generally agreed that the trend toward reduced-tillage and less summerfallow in the Prairies is attributable to several factors besides soil conservation, including reduced labour, energy and machinery requirements, better weed control options and increased moisture efficiency. Producers have been able to capitalize on new seeding equipment that is capable of seeding and applying fertilizer in one pass, even with high residues. These benefits, combined with the fact that 40% of the area still uses conventional tillage, suggest that the current trend toward conservation tillage is likely to continue, spurring a further decline in the wind erosion risk.

■ REFERENCES

McConkey, B., T. McInnis, and W. Eilers, 2000. *Environmentally Sustainable Production Practices for Diversified Cropping Systems in the Semiarid Prairie* – Final Report for the Canada-Saskatchewan Agri-Food Innovation Fund (Project 96000486). Agriculture and Agri-Food Canada, Semiarid Prairie Agricultural Research Centre, Swift Current (Sask.).

Moulin, A.P., and R. Beimuts, 2000. *Residue Tillage (Decision) Support System* (RTDS) *Version 1.1*. Documentation. Agriculture and Agri-Food Canada, Brandon (Man.).

Woodruff, N.P., and F.H. Siddoway, 1965. *A Wind Erosion Equation*. Soil Science Society of America Proceedings. 29 (5): 602-608.

C) Tillage Erosion

SUMMARY

Tillage erosion is a significant form of soil erosion that has caused considerable degradation of soils and landscapes across the country. Results from the Tillage Erosion Risk Indicator reveal that, between 1981 and 2001, the risk of tillage erosion in Canada decreased by nearly 50%, a substantial decline. In 2001, almost 50% of cropland was at very low risk of tillage erosion. This positive trend is attributable mainly to the decline in the erosivity *of tillage practices (e.g. increase in no-till). However, erosive tillage practices persist in some regions including some with highly erodible landscapes (e.g. Ontario, Prince Edward Island, New Brunswick).*

AUTHOR:
D. Lobb

INDICATOR NAME:
Risk of Tillage Erosion

STATUS:
National coverage, 1981 to 2001

THE ISSUE

Many farm implements move soil and, on sloping land, this movement is influenced by gravity, causing more soil to be moved when soil is tilled downslope than when tilled upslope. Even when tilling is done across the slope, more soil will be moved downslope than upslope. The resulting progressive downslope movement of soil from hilltops and soil accumulation at the base of hills is called tillage erosion (Govers et al. 1999). Evidence of tillage erosion is ubiquitous on hilly land. This form of erosion is most severe on land that has many short, steep slopes and in areas where intensive cropping and tillage practices are used. Although distinct from wind and water erosion, tillage erosion influences wind and water erosion by exposing the subsoil, which is more sensitive to these erosion processes, and by delivering soil to portions of the landscape where water erosion is most intense. As such, tillage erosion also contributes to the off-site environmental impacts of soil erosion.

THE INDICATOR

The Tillage Erosion Risk Indicator (TillERI) is used to assess how the risk of soil degradation from tillage erosion on cultivated agricultural lands is changing relative to changes in land management. Tillage erosion is a function of the erodibility of the landscape and the erosivity of the tillage system used. Hilly landscapes with short, steep slopes are highly erodible. An example is steep hummocky landscapes. Crops that are frequently tilled with implements that move large amounts of soil over great distances are highly erosive. Conventionally tilled potato production is an example.

The rate of soil loss by tillage erosion is calculated and reported in five risk classes, corresponding to five erosion rate classes: very low (less than 6 tonnes per hectare per year), low (6 to 11 t ha^{-1} yr^{-1}), moderate (11 to 22 t ha^{-1} yr^{-1}), high (22 to 33 t ha^{-1} yr^{-1}) and very high (greater than 33 t ha^{-1} yr^{-1}). Areas in the very low risk class are considered capable of sustaining long-term crop production and maintaining agri-environmental health, under current conditions. The other four classes represent the risk of unsustainable conditions that call for soil conservation practices to support crop production over the long term and to reduce water quality impacts. The performance objective for this indicator is to increase the proportion of cropland in the very low risk class.

CALCULATION METHOD

The model that underlies the Tillage Erosion Risk Indicator was developed by Lobb (1997). The rate of soil loss by tillage erosion is calculated by multiplying tillage erosivity and landscape erodibility together. This rate is calculated for individual Soil Landscape of Canada polygons. For analysis and reporting purposes, tillage erosivity, landscape erodibility and tillage erosion values are aggregated, or scaled up to provincial, regional and national levels.

Tillage erosivity is ascertained for each Soil Landscape of Canada (SLC v 3.0) polygon from the cropping and tillage practices reported in the Census of Agriculture database. Cropping and tillage practices in this database are grouped in classes (e.g. grain corn under conventional tillage, grain corn under conservation tillage or grain corn under no-till). Erosivity values are assigned to each class based on the character of the tillage operations representing each class of tillage and cropping system within the various agroecosystems across Canada, and based on experimental data (Lobb et al. 1995, 1999).

Each SLC polygon is characterized by one or more representative landforms, and each landform is characterized by hillslope segments (upper, mid and lower slopes and depression), and each hillslope segment is characterized by a slope gradient and slope length. Landscape erodibility values are calculated for each landform as a function of the gradient of the mid-slope (the maximum slope gradient, which determines the total soil loss on a landform), the length of the upper slope (the convex portion of the landform, which determines the area over which soil is lost) and the total slope length (which determines the density of hillslopes within a given area). Landform data and the associated topographic data were obtained from the National Soil DataBase.

There was a steady decrease in the risk of tillage erosion in Canada between 1981 and 2001.

■ LIMITATIONS

In comparison to other soil erosion processes, there are very few experimental data on tillage erosion. Tillage erosivity values for the classes of cropping and tillage systems are estimates generated from a few experiments carried out in Canada and elsewhere around the world and from expert opinion on the character of the tillage operations representing each class of tillage and cropping system. The landform data used to derive landscape erodibility values have not been adequately verified. Landforms are represented by simple, two-dimensional hillslopes; as such, the landform data do not reflect the topographic complexity that exists for some landforms. It is assumed that soil loss by tillage erosion is uniformly distributed over convex portions of landforms and that there are no field boundaries over the length of hillslopes. Within each SLC polygon, it is assumed that crops are distributed evenly between and over the landforms within the polygon.

The ability of the Tillage Erosion Risk Indicator to make accurate assessments will be enhanced as the body of research on tillage erosivity expands, and as the landform data undergo more rigorous verification. Through this research and through validation of the indicator results, it will be possible to assess the certainty of the indicator findings. As well, there is a need to better understand how soil erosion processes interact. It is known that soil losses caused by tillage erosion increase the erosive potential of the soil in response to wind and water; and soil eroded by tillage erosion is delivered to areas of the landscape where water erosion is most intense. A better understanding of these interactions will lead to a more comprehensive and more accurate assessment of soil erosion risk.

■ RESULTS

The risk of tillage erosion in Canada and in each province is shown for 1981, 1986, 1991, 1996 and 2001 in Table 13-3. Figure 13-3 shows the distribution of the various risk classes in Western and Eastern Canada in 2001.

Canada: There was a steady decrease in the risk of tillage erosion in Canada between 1981 and 2001. In that period, a 43% reduction in tillage erosivity resulted in a 48% reduction in tillage erosion. (Only minor changes occur in landscape erodibility, resulting from changes in cropped land.) The majority of this change occurred between 1996 and 2001. In 2001, almost 50% of Canadian cropland was in the very low, or "sustainable," tillage erosion risk class, a considerable improvement over the 1981 level (38%).

British Columbia: British Columbia followed the national trend, with a 25% decrease in tillage erosivity between 1981 and 2001 and an attendant 27% decrease in tillage erosion. The proportion of cropland in the very low risk class increased from 20% in 1981 to 34% in 2001.

Table 13-3: Share of cropland in various tillage erosion risk classes, 1981 to 2001

Share of Cropland in Different Tillage Erosion Risk Classes (in %)

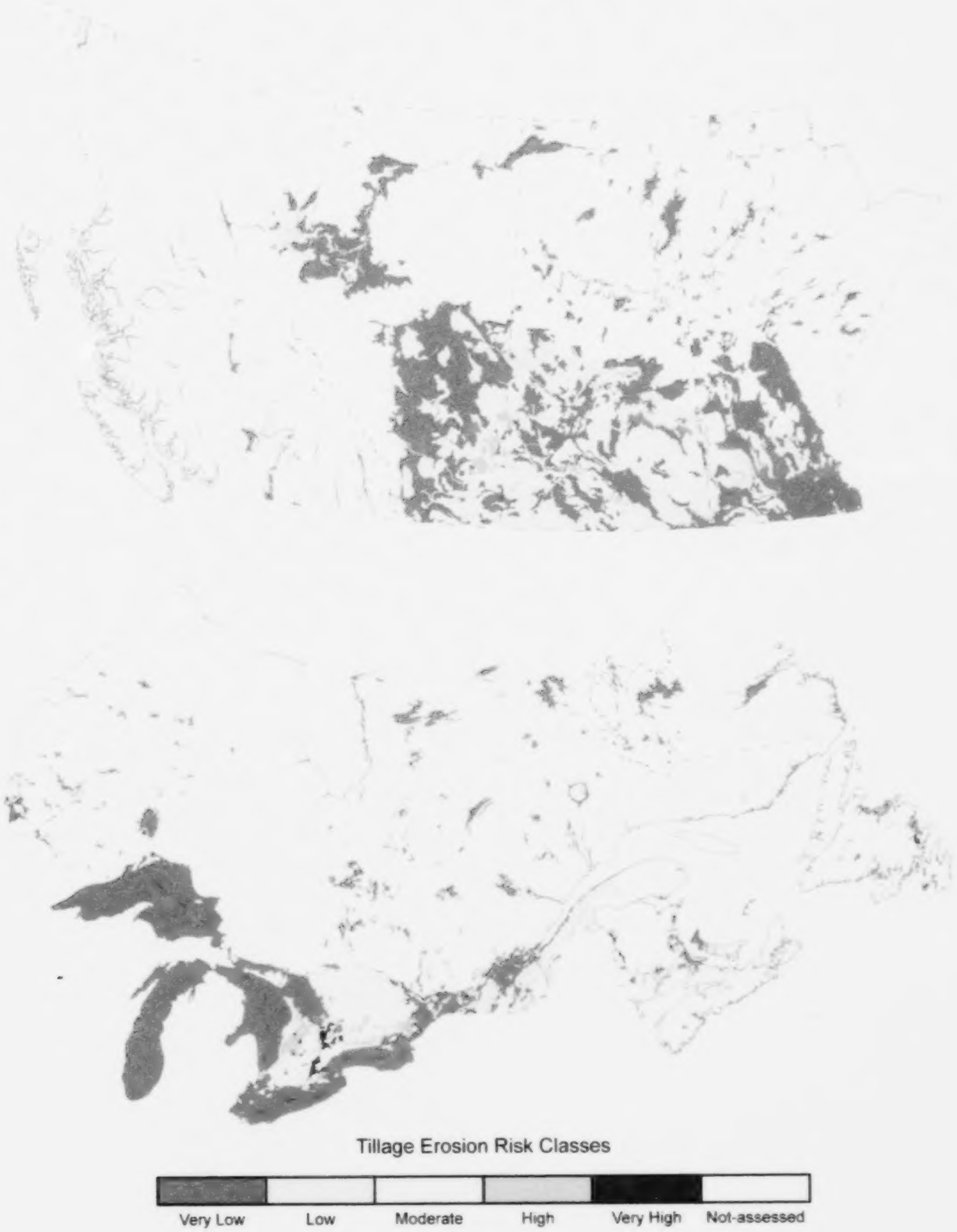
	Very Low					Low					Moderate					High					Very High				
Province	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**
BC	20	20	21	32	34	38	36	43	39	40	38	36	29	29	26	3	8	7	1	1	1	<1	<1	<1	0
Prairies	40	40	42	45	53	9	12	15	21	27	28	29	29	29	19	16	15	12	4	1	7	4	1	<1	0
AB	57	56	60	63	71	9	10	12	17	16	21	22	20	16	11	6	9	7	3	1	6	3	<1	1	0
SK	24	25	27	30	38	8	13	15	22	34	34	35	38	41	26	23	21	18	6	1	10	6	2	<1	0
MB	63	62	62	64	66	13	14	26	26	25	18	19	11	10	10	6	5	2	<1	<1	<1	0	0	0	0
ON	16	16	17	26	28	18	19	19	9	8	25	26	31	47	48	33	32	27	13	11	8	7	6	5	4
QC	61	58	57	47	45	20	26	28	40	39	17	13	12	10	13	2	2	2	2	2	1	1	1	1	1
Atlantic	20	25	25	25	25	25	31	26	26	26	51	40	45	42	42	2	4	4	5	6	2	0	<1	2	<1
NB	36	46	46	43	45	26	33	33	38	33	32	13	13	13	14	1	8	8	0	8	5	0	0	6	0
NS	4	5	5	11	12	29	45	58	55	58	65	50	36	31	29	1	0	0	3	0	0	0	0	0	0
PEI	18	19	19	19	18	23	21	<1	<1	<1	55	56	77	70	72	4	4	3	10	9	0	0	0	0	0
NL	30	0	15	17	14	0	0	49	48	48	58	100	6	0	25	12	0	16	25	0	0	0	15	10	12
Canada	**38**	**39**	**40**	**43**	**50**	**11**	**14**	**17**	**21**	**26**	**27**	**28**	**28**	**30**	**22**	**16**	**16**	**13**	**5**	**2**	**7**	**4**	**2**	**1**	**0**

Prairie Provinces: The three Prairie Provinces exhibited the greatest change in tillage erosion risk and made the largest contribution to the changes observed nationally. Although all three provinces saw a reduction in tillage erosion risk, Saskatchewan and Alberta posted the greatest increase in cropland in the very low risk class, going from 24% in 1981 to 38% in 2001 and from 57% in 1981 to 71% in 2001, respectively. Manitoba posted a more modest reduction in tillage erosion risk: the proportion of land in the very low risk class rose from 63% to 66% between 1981 and 2001. Note that Alberta and Manitoba are the only two provinces with more than 50% of cropland in the very low risk class. The high proportion of Manitoba cropland in the very low erosion risk class can be explained by the fact that the bulk of cropland is on landscapes that are not highly erodible, in the Red River Valley: 70% of cropland in this province is classified as having very low landscape erodibility. The most notable trend in the Prairie Provinces is the shift of cropland from the moderate and high risk classes to the low risk class. This shift accounts for the major reductions observed in tillage erosion—decreases of 48%, 55% and 29% between 1981 and 2001 in Alberta, Saskatchewan and Manitoba, respectively.

Ontario: Considerable changes occurred in the area of Ontario cropland in all five tillage erosion risk classes between 1981 and 2001. Cropland area in the very high risk class decreased from 8% to 4%, and the area in the high risk class decreased from 33% to 12%. As well, the area in the low risk class decreased from 18% to 8%. These improvements were offset by increases in both the moderate and very low risk classes, from 25% to 49% and from 16% to 28%, respectively. Overall, tillage erosivity decreased by 26% and tillage erosion by 25% between 1981 and 2001. Ontario nonetheless has the greatest proportion of cropland in the high erosion risk classes (16% in 2001).

Quebec: The majority of cropland in Quebec is on landscapes that are not highly erodible, within the St. Lawrence Lowlands: 70% of cropland in this province is classified as having very low landscape erodibility. Consequently, even though tillage erosivity has steadily increased (13% between 1981 and 2001), tillage erosion remained virtually unchanged. The area of cropland in the very low tillage erosion risk class decreased from 61% to 45% with an accompanying increase from 20% to 39% in the low risk class. Very little change occurred in the higher risk classes.

Figure 13-3: Risk of Tilage Erosion on cultivated land in Canada under 2001 management practices


Tillage Erosion Risk Classes
Very Low
Low
Moderate
High
Very High
Not-assessed

Atlantic Provinces: Between 1981 and 2001, there was very little reduction in tillage erosivity in the Atlantic Provinces (6%); consequently, the reduction in tillage erosion is minimal (3%). The area of cropland in the very low tillage erosion risk class is relatively small and only increased from 20% to 25%. With 26% of cropland area in the low risk class throughout the period, about 50% of the cropland was at moderate to very high risk of tillage erosion (54% in 1981 versus 49% in 2001).

The results for individual provinces in the Atlantic Region differ greatly. Tillage erosivity and tillage erosion increased in both Prince Edward Island (erosion increase of 19%) and Newfoundland and Labrador (erosion increase of 14%), whereas they decreased in New Brunswick (erosion decrease of 17%) and Nova Scotia (erosion decrease of 24%). New Brunswick saw increases in cropland area in the very low (36% in 1981 versus 45% in 2001) and low (26% versus 34%) tillage erosion risk classes, and a decrease in the higher risk classes, particularly the moderate risk class (32% in 1981 versus 14% in 2001). In contrast, the area of Prince Edward Island cropland increased in the moderate (55% versus 72%) and high (4% versus 9%) risk classes. The area in the low erosion risk class decreased from 23% in 1981 to 0% in 2001, but there was no change in the very low (18% from 1981 to 2001) and very high (0%) risk classes.

■ INTERPRETATION

Canada: The decrease in tillage erosion risk in Canada is linked to a decrease in tillage erosivity. Landscape erodibility varies greatly from region to region across the country, but it does not change over time. The slight changes in landscape erodibility that do occur are the result of land moving into and out of crop production. Consequently, it is the change in the erosivity of tillage practices that drives the changes observed in tillage erosion. Decreases in tillage erosivity and, therefore, tillage erosion result from the adoption of conservation tillage practices and/or the growing of crops that require less tillage. The decrease in tillage erosion in Canada is largely due to the widespread adoption of conservation tillage practices (60% of seeded land in 2001), particularly no-till systems (representing half of the land in conservation tillage), in most provinces. Changes in crops grown were less of a contributing factor. Crops requiring more intensive tillage, making them more erosive, such as corn, potatoes and beans, increased in area and as a share of cropland in specific reporting years, from 6% in 1981 to 15% in 2001. This uptrend was offset by the decrease in summerfallow, from 22% in 1981 to 12% in 2001, and by the increase in crops requiring very little tillage such as alfalfa and hay, from 13% in 1981 to 18% in 2001. By far, the most dominant crops are cereals, making up nearly 60% of cropland in all reporting years. Although most crops have seen a reduction in tillage intensity, the adoption of direct-seeding (no-till/zero-till) in cereals has had the greatest influence on tillage erosivity and tillage erosion, owing to the large share of cropland devoted to cereals. Although improvements in tillage erosion risk have been made since 1981, less than 50% of Canada's cropland was in the very low risk class in 2001.

British Columbia: British Columbia has had a steady decrease in tillage erosivity and an accompanying decline in tillage erosion risk. The primary cause for this improvement has been the conversion from crops requiring intensive tillage to crops requiring very little tillage, rather than the adoption of conservation tillage. Cropping changes were dominated by the reduction in cereals from 49% of cropland in 1981 to 20% in 2001, and the increase in alfalfa and hay from 39% in 1981 to 66% in 2001. The adoption of conservation tillage practices has been relatively limited, with 21% of seeded area in conservation tillage in 2001 and 14% direct-seeded (no-till) in 2001. Changes in this province, which has less than 1% of Canada's cropland, are not reflected in the national analysis.

Prairies: Given their large share of Canada's cropland (85%), the Prairie Provinces dominate the national analysis; consequently, the interpretation of this region's results dominates the national interpretation. The decrease in tillage erosivity and, therefore, tillage erosion is attributable in part to the reduction in land under summerfallow: reductions from 12% to 5%, 36%

to 17% and 19% to 11% were recorded between 1981 and 2001 in Manitoba, Saskatchewan and Alberta, respectively. The increased adoption of direct-seeding (13%, 39% and 27% of seeded land in 2001 in Manitoba, Saskatchewan and Alberta, respectively) is largely responsible for the decrease in tillage erosivity and tillage erosion. While more modest improvements occurred in Manitoba than in Alberta and Saskatchewan, much of the cropland in this province (70%) is classified as having very low landscape erodibility and therefore the risk of tillage erosion is low, even with intensive tillage.

Ontario: Between 1981 and 2001, Ontario had one of the highest levels of tillage erosivity and tillage erosion in the country. This can be explained by the high proportion of intensively tilled crops (e.g., corn and soybeans) grown here. The share of land planted to such crops increased from 39% to 56% between 1981 and 2001. This increase is largely linked to a tripling of the area seeded to soybeans. Although the area of these crops increased, the intensity of tillage used to grow them decreased as conservation tillage practices were implemented, causing overall decreases in tillage erosivity and tillage erosion.

Quebec: The risk of tillage erosion in Quebec remained relatively low and nearly constant over the 20-year period studied. The low levels of tillage erosion and the lack of change can be explained by the fact that a large portion of the cropped land is nearly level and hence not very erodible. In 2001, this province had one of the highest tillage erosivity levels in the country and it was one of only two provinces to see an increase in tillage erosivity (increase of 13% since 1981). This increase in tillage erosivity resulted from an increase in the area seeded to corn and soybeans (10% of seeded area in 1981 versus 35% in 2001). The adoption of conservation tillage practices for these crops has limited the increase in tillage erosivity to 13%, and since these crops are seeded on land with very low erodibility, there has been very little change in tillage erosion.

Atlantic Provinces: The tillage erosion risk in this region is a concern—highly erosive cropping and tillage systems (i.e. potato production) are often used on highly erodible landscapes. The levels of tillage erosion have remained relatively high, with only a slight decrease in tillage erosion between 1981 and 2001. There have been considerable improvements in New Brunswick and Nova Scotia, but they are offset by the change in Prince Edward Island. Note that owing to its small area of cropland, the changes in Newfoundland and Labrador are difficult to interpret and have little influence on the regional results. In New Brunswick between 1981 and 2001, there was a 9% increase in the area of potato crops, an 8% increase in alfalfa and hay and a 28% increase in cereals. This change in crops, accompanied by a modest reduction in tillage intensity, resulted in a 17% reduction in tillage erosion. By contrast, Prince Edward Island posted a 68% increase in the area of potato crops, a 14% increase in alfalfa and hay and a 14% decrease in cereals. These changes, accompanied by a modest reduction in tillage intensity, spelled a 19% increase in tillage erosion. Potato production is highly erosive, even when conservation tillage practices are used. Consequently, changes in the area of potato crops greatly influence tillage erosion trends.

■ RESPONSE OPTIONS

Efforts to reduce tillage erosion should be focused on landscapes that are hilly and therefore more susceptible to tillage erosion. Tillage erosion is controlled by modifying tillage practices. By eliminating tillage, tillage erosion can be stopped. The adoption of a no-till cropping system or the growing of crops that require no tillage, such as forage, are the most effective means of reducing tillage erosion. However, even practices such as seeding and fertilizer injection can cause significant levels of soil movement and tillage erosion.

Many cropping systems, such as potatoes, will always entail some form of soil disturbance leading to soil movement and tillage erosion. In these production systems, it is important to select tillage implements and carry out tillage practices in a way that minimizes tillage erosion. Implements that move less soil and move it over a shorter distance will generate less tillage erosion. More uniform speed and depth of operation will lessen tillage erosion. In landscapes where contour tillage is practical, this approach may result in less tillage erosion than tilling up and down hillslopes, particularly if greater uniformity of tillage depth and speed can be achieved by tilling along the contours.

Tillage practices that are effective in controlling wind and water erosion are not necessarily effective in controlling tillage erosion. For example, the chisel plough leaves more crop residues on the soil surface than the moldboard plough, providing more protection against wind and water erosion; however, the chisel plough can move soil over a much greater distance and cause more tillage erosion. In fact, a rollover moldboard plough can be a very effective conservation tool when the furrow is thrown upslope. The upslope movement of soil by the moldboard plough may offset the downslope movement by other tillage operations. Fence lines, *shelterbelts*, water diversion terraces and so on may reduce wind and water erosion, but they result in more widespread soil losses associated with tillage erosion.

Although it is possible to stop tillage erosion, extraordinary measures may be required if there is a long history of tillage erosion. The landscape areas that are subject to the most severe soil losses, specifically hilltops, also have the poorest ability to regenerate topsoil. Some farmers focus manure application on these areas to enhance soil regeneration. Other farmers remove soil that has accumulated at the base of hills and apply it to these severely eroded areas to restore the landscape.

■ REFERENCES

Govers, G., D.A. Lobb, and T.A. Quine, 1999. *Tillage Erosion and Translocation: Emergence of a New Paradigm in Soil Erosion Research.* Journal of Soil and Tillage Research. 51 (3-4): 167-174.

Lobb, D.A., Tillage 1997. *Erosion Risk Indicator. Methodology and Progress Report. Agri-Environmental Indicator Project.* Agriculture and Agri-Food Canada, Ottawa (Ont.).

Lobb, D.A., R.G. Kachanoski, and M.H. Miller, 1995. *Tillage Translocation and Tillage Erosion on Shoulder Slope Landscape Positions Measured Using ^{137}Cs as a Tracer.* Canadian Journal of Soil Science. 75: 211-218.

Lobb, D.A., and R.G. Kachanoski, 1999. *Modelling Tillage Erosion on the Topographically Complex Landscapes of Southwestern Ontario.* Journal of Soil and Tillage Research. 51: 261-277.

Lobb, D.A., R.G. Kachanoski, and M.H. Miller, 1999. *Tillage Translocation and Tillage Erosion in the Complex Upland Landscapes of Southwestern Ontario.* Journal of Soil and Tillage Research. 51: 189-209.

14. Soil Organic Carbon

AUTHORS:

B. McConkey,
J. Hutchinson,
W. Smith,
B. Grant and
R. Desjardins

INDICATOR NAME:

Soil Organic Carbon Change

STATUS:

National coverage, 1981 to 2001

SUMMARY

Soil organic matter is related to many important aspects of soil quality and is a key component of good soil health and fertility. An indicator—the Soil Organic Carbon Change Indicator—has been developed to assess how organic carbon levels are changing over time in Canadian agricultural soils. The change in soil organic carbon (SOC) is a useful indicator of general soil health and also serves to estimate how much carbon dioxide is removed from the atmosphere and sequestered in agricultural soils. The rate of soil organic carbon change is estimated by incorporating generalized scenarios of past and current land-use and management practices into the Century simulation model.

The results indicate that, in terms of soil organic carbon, Canada's cropland has gone from a net loss position in 1991 and earlier years to a net gain situation since 1996. Most of the gains have occurred on the Prairies, where the increased adoption of reduced tillage, the reduction in summerfallow and the increase in hay crops all have helped to replenish soil organic matter. Overall, the mean rate of SOC change on Canada's cropland in 2001 was 29 kg ha^{-1} yr^{-1}. This rate suggests that Canada's cropland operated as a net sink of 4.4 Mt of carbon dioxide (CO_2) *that year. Despite the general good news story of increasing SOC, 15% of Canada's cropland was predicted to undergo a large decrease in soil organic carbon (losses of 50 kg ha^{-1} yr^{-1} or greater).*

THE ISSUE

Carbon (C) is the basic building block of all living things and the main component of soil organic matter. Carbon is first captured from the air as carbon dioxide by plants during *photosynthesis*. This carbon enters the soil upon the death of plants or of animals that directly or indirectly ate the plants. Most of this carbon is quickly returned to the atmosphere during initial decomposition of the plant and animal remains. However, through the decomposition process, a small portion of organic carbon from plant and animals becomes soil organic materials that are less easily decomposed. Over time, soil organic matter builds in the soil until a "steady-state" level of soil organic matter is reached when new organic carbon additions from dead plants and animals exactly balance losses of organic carbon from decomposition. Soil organic matter is generally considered to be 58% carbon by mass so the terms soil organic carbon and soil organic matter are used interchangeably.

Soil organic matter strongly influences many important aspects of soil quality and is a key component of good soil health. It helps hold soil particles together and stabilizes the soil structure, making the soil less prone to erosion and improving the ability of the soil to store and convey air and water. The improved soil structure helps make the soil more workable and maintain an uncompacted state. Soil organic matter stores and supplies many nutrients needed for the growth of plants and soil organisms. It binds potentially harmful substances, such as heavy metals and pesticides. Finally, it acts as storage for carbon dioxide (a major greenhouse gas) captured from the atmosphere.

Losses of soil organic matter, contribute to degraded soil structure, increased soil vulnerability to erosion and lower fertility, ultimately leading to lower yields and reduced sustainability of the soil resource.

THE INDICATOR

The Soil Organic Carbon Change Indicator has been developed to assess how organic carbon levels are changing over time in Canadian agricultural soils. The indicator estimates the rate of change in soil organic carbon and provides an estimate of current levels of soil organic carbon, considering the effects of present land use and management practices. The change in soil organic carbon is a useful indicator of long-term trends in general soil health. The indicator also serves to estimate how much carbon dioxide is removed from the atmosphere by plants and stored (or sequestered) as SOC in agricultural soils. Thus, in addition to indicating change in soil health, the change in SOC also provides an indication of the potential reduction in atmospheric CO_2 that can offset some CO_2 emissions from the burning of fossil fuels.

The indicator results are given as the percentage of total cropland that falls into each of five different SOC change classes expressed in kg ha^{-1} yr^{-1} (kilograms per hectare per year). Negative values represent a loss of SOC from the soil and positive values represent a gain of SOC. The five classes are defined as follows: large increase (gain more than 50 kg ha^{-1} yr^{-1}), moderate increase (10 to 50 kg ha^{-1} yr^{-1}), negligible to small change (-10 to 10 kg ha^{-1} yr^{-1}), moderate decrease (-10 to -50 kg ha^{-1} yr^{-1}) and large decrease (losses more than -50 kg ha^{-1} yr^{-1}). If soil is well managed over a long time period, the soil organic matter should show little change over time. Thus increasing soil organic carbon is not necessarily preferred over a situation of no change. However, if the soil has been degraded in the past, a significant increase in SOC is clearly desirable as it indicates that the soil is being restored to better soil health and function. Therefore, the preferred values for this indicator are no loss of soil organic carbon in all agricultural soils and carbon accumulation in soils where those soils were low in organic matter.

For Canada as a whole, there has been a dramatic shift from a net loss position for SOC during the 1980s to a general uptrend in SOC levels in 2001.

CALCULATION METHOD

Indicator calculation is based on the methodology of Smith et al. (1997; 2000). Briefly, the indicator uses version 4 of the Century model (Parton et al. 1987; 1988) to predict the rate of change in organic carbon in Canada's agricultural soils. The Century model is a computer simulation tool that uses simplified soil–plant–climate relationships to describe the dynamics of soil carbon and nitrogen in grasslands, croplands, forests and savannas. It simulates above- and below-ground production of plant material as a function of soil temperature and water and nutrient availability. This model has been tested extensively under different soil, climatic and agricultural practices such as planting, fertilizer application, tillage, grazing and organic matter addition.

Deriving the indicator requires data on several agricultural management practices, including crop rotation, fertilizer application and tillage. Much of the information on cropland management, such as tillage and crop proportions, was obtained from the Census of Agriculture. Soil data were taken from the Canadian Soil Information System (CANSIS) and climate data were obtained from weather stations within the Soil Landscape of Canada (SLC) polygons. The erosion calculations were based on the assumption that 15% of eroded soil is transported out of the agricultural landscape by watercourses except on the Prairies (Alberta, Saskatchewan and Manitoba), where it is assumed that erosion only redistributes soil within the farmed landscape. Erosion rates were taken from calculations of the Indicator for Risk of Water Erosion (Shelton et al. 2000).

Simulations were performed on a sample (15%) of Canada's agricultural soils, chosen to be representative of various soil types and textures across Canada. They encompassed multiple soil landscape polygons and were scaled up to the provincial level. The rate of SOC change was determined for the years 1981, 1986, 1991, 1996 and 2001, by taking the slope of a 10-year regression centred on each particular year, to account for rotations several years long.

LIMITATIONS

The calculation method is based on taking a sampling of SLC polygons and using highly generalized scenarios of past, current and future cropland management. Although a single SOC change rate is calculated for each SLC polygon, within any given SLC polygon, there will be areas of decreasing, stable and increasing SOC because of differing management practices at the farm and field levels. The ability of a single SLC polygon rate to integrate the full range of changes is uncertain. Therefore, the Soil Organic Carbon Change Indicator is only suitable for regional or provincial assessments and not applicable to the farm level.

Owing to uncertainty regarding the performance of the Century model, manure application and irrigation were disregarded in the simulations, both of which can affect the results. Short-term pasture in the crop rotation was not considered due to gaps in the information needed to model such pastures.

Although the Century model was calibrated and validated for a number of sites for which experimental data on long-term SOC change were available, it was not feasible to carefully check all the model results. Many combinations of past land use and management practices affect the current SOC status and the rate of change, but these are often not adequately represented by generalized input scenarios. Considerable research is under way to refine the accounting methods for carbon change in agricultural soils because of the important role these soils can play in removing CO_2 from the atmosphere.

■ RESULTS

Mean rates of SOC change are summarized in Figure 14-1. Table 14-1 shows the proportion of agricultural land in Canada that falls into the five rated classes of soil organic carbon change.

Canada: For Canada as a whole, there has been a dramatic shift from a net loss position for SOC during the 1980s to a general uptrend in SOC levels in 2001. It is estimated that, in 1991, most of Canada's cropland (64%) was in either the moderate SOC decrease class or the large decrease class. By 2001, however, the majority of Canada's cropland (53%) was in the moderate or large increase class. Nonetheless, 34% of total cropland was still in the moderate to large decrease classes in 2001. Mean rates of SOC change in Canada were -53, -51, -34, 2.4 and 29 kg of carbon per hectare in 1981, 1986, 1991, 1996 and 2001, respectively.

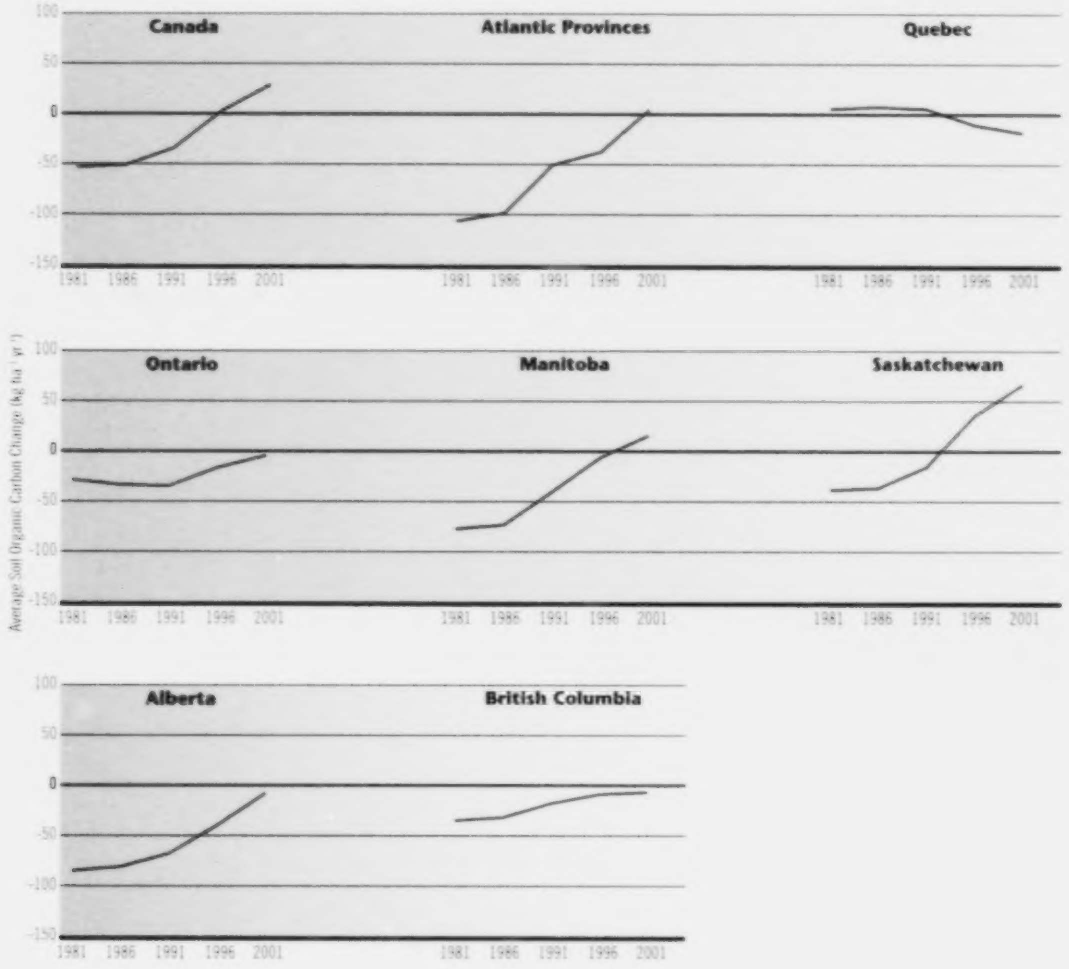
British Columbia: Soil organic carbon showed an increase for 38% of cropland (moderate: 11%; large: 27%) in 2001. This compares to a rising SOC level for 32% of cropland in 1981. Negligible to small changes occurred on 34% of cropland, and SOC was decreasing on 28% (moderate: 14%; large: 14%).

Table 14-1: Share of cropland in different Soil Organic Carbon (SOC) change classes, 1981 to 2001

Share of Cropland in Different SOC Change Classes (in %)

Province	Large increase (more than 50 kg ha^{-1} yr^{-1})					Moderate increase (10 to 50 kg ha^{-1} yr^{-1})					Negligible to small change (-10 to 10 kg ha^{-1} yr^{-1})					Moderate decrease (-10 to -50 kg ha^{-1} yr^{-1})					Large decrease (loss more than -50 kg/ha/yr)				
	81	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**
BC	7	7	7	11	11	25	25	34	27	27	27	27	27	34	34	21	21	18	14	14	20	20	14	14	14
Prairies	6	5	10	28	35	11	13	16	21	23	8	8	11	9	14	20	20	23	18	17	56	54	41	25	12
AB	8	7	5	12	11	8	8	10	10	18	5	8	8	7	18	11	8	10	17	23	68	69	67	54	30
SK	3	2	11	38	46	14	16	20	26	29	11	10	14	12	13	26	29	33	18	10	47	43	22	6	2
MB	11	9	15	25	44	9	13	13	23	8	3	2	5	3	8	14	13	11	19	28	63	63	56	30	12
ON	4	5	2	3	13	13	18	13	3	17	20	14	12	17	12	27	31	47	52	39	36	32	26	25	19
QC	9	9	9	9	9	9	8	8	8	8	18	17	17	0	0	24	24	24	17	17	41	42	42	66	66
Atlantic Prov.	22	22	35	35	43	21	21	10	10	10	10	10	8	8	8	11	11	23	23	23	36	36	24	24	16
Canada	**6**	**5**	**9**	**25**	**31**	**12**	**14**	**15**	**18**	**21**	**10**	**9**	**11**	**10**	**13**	**20**	**21**	**25**	**21**	**19**	**53**	**51**	**39**	**26**	**15**

Figure 14-1: Average SOC change over time across Canada



Alberta: Soil organic carbon was on the rise for 29% of cropland (moderate: 18%; large 11%) in 2001. This compares to a rising SOC level for 17% of cropland in 1981. Negligible to small changes occurred on 18% of cropland and a decrease in SOC on 53% (moderate: 23%; large: 30%).

Saskatchewan: Soil organic carbon was increasing for 75% of cropland (moderate: 29%; large 46%) in 2001. This compares to increasing SOC for 17% of cropland in 1981. Negligible to small changes occurred on 13% of cropland, and a decrease in SOC on 12% (moderate: 10%; large: 2%).

Manitoba: Soil organic carbon showed an uptrend for 52% of cropland (moderate: 8%; large: 44%) in 2001. This compares to increasing SOC for 20% of cropland in 1981. Negligible to small changes occurred on 8% of cropland and a decrease in SOC on 40% (moderate: 28%; large: 12%).

Ontario: Soil organic carbon was on the rise for 30% of cropland (moderate: 17%; large 13%) in 2001. This compares to increasing SOC for 17% of cropland in 1981. Negligible to small changes occurred on 12% of cropland and a decrease in SOC on 58% (moderate: 39%; large: 19%).

Quebec: Soil organic carbon was increasing for 17% of cropland (moderate: 8%; large 9%) in 2001. This compares to increasing SOC for 18% of cropland in 1981. No negligible to small changes were recorded, and SOC was decreasing on 83% of cropland (moderate: 17%; large: 66%).

Atlantic Provinces: Soil organic carbon was increasing for 53% of cropland (moderate: 10%; large: 43%) in 2001. This compares to increasing SOC for 43% of cropland in 1981. Negligible to small changes occurred on 8% of cropland, and SOC was decreasing on 39% (moderate: 23%; large: 16%).

■ INTERPRETATION

Canada: The Soil Organic Carbon Change Indicator clearly shows the beneficial effects that improvements in farm management have had on agricultural soils in Canada over the last 15 years or so. The general uptrend in soil organic carbon since 1986 can be attributed to three main changes in cropland management: reduction in tillage intensity (especially increased no-till) in all provinces, a reduction in summerfallow on the Prairies and an increase in hay and forage crops in most provinces.

The indicator does not provide a rigorous or complete inventory of SOC changes like the kind that would be needed to achieve a precise assessment of how Canada's cropland is affecting the atmospheric CO_2 balance. Nevertheless, the indicator suggests that Canada's cropland went from being a net source of 5.1 Mt of CO_2 per year in 1991 to a net sink of 4.4 Mt of CO_2 per year by 2001. This represents an additional environmental benefit of enhanced cropland management practices.

Western Canada

Prairies: The general situation on the Prairies is that past practices such as frequent summerfallow, intensive tillage and few hay or forage crops significantly degraded soil organic matter. The two goals for soil organic carbon change should be: (1) to stop soil organic carbon loss, especially where significant degradation is occurring, and (2) to attain soil organic carbon change rates that correspond to the moderate or large increase classes and that can reverse SOC degradation.

Recent changes in cropland management, including the adoption of reduced (AB: 36%; SK: 29%; MB: 33%) or no-tillage practices (AB: 27%; SK: 39%, MB: 13%), the reduction in summerfallow (e.g. between 1991 and 2001, summerfallow decreased from 16% to 11% of cropland in AB, from 30% to 17% in SK, and from 6% to 5% in MB) and the increase in hay and forage crops (e.g. between 1991 and 2001, these crops increased from 16% to 24% of cropland in AB, from 5% to 9% in SK and from 14% to 19% in MB) have either halted soil organic carbon loss or produced soil organic carbon gains. The Soil Organic Carbon Change Indicator shows a dramatic shift in the Prairie provinces between 1991 and 2001 from a carbon loss position to a gain position. Relatively little land fell into the "negligible to small change" class. However, the soil organic carbon gains on the Prairies will not continue indefinitely. It is predicted that, within a decade or two, the rate of gain will decrease as the soils approach a new "steady-state" SOC level on more cropland.

British Columbia: Like the Prairie provinces, British Columbia has increased the area of forage crops (e.g. from 53% to 67% of cropland between 1991 and 2001) and reduced summerfallow (from 9% in 1991 to 6% in 2001). Although the rate of reduced tillage adoption has not been as great as in the Prairies, the proportion of land on which reduced or no-till approaches were applied increased from 17% in 1991 to 36% in 2001. Concurrently with these changes in management practices, the average SOC change situation went from a moderate loss in 1991 and earlier years to a small change in 2001.

Eastern Canada

Overall, there has been less SOC degradation in the eastern provinces compared with the western provinces, since farming practices historically have involved more cropland devoted to hay production and no use of summerfallow. Therefore, in the eastern provinces, large increases in soil organic carbon are not generally expected, except on land where soil organic carbon has become severely depleted due to excessive erosion. The three goals for Eastern Canada should therefore be: (1) to stop soil organic carbon loss, especially where the rate of loss is significant; (2) to increase soil organic carbon wherever there has been significant loss; and (3) to maintain soil organic carbon levels.

One-third (33%) of the cropland in the eastern provinces is predicted to experience a large decrease in soil organic carbon. This problem is primarily due to SOC loss due to excessive erosion on cropland with annual crops. Stopping excessive erosion is the recommended action to maintain and improve soil health and function.

Quebec is the only province that showed a pattern opposite to the national trend, having had moderate soil organic carbon increases during the 1980s followed by moderate SOC decreases. Among the eastern provinces, Quebec alone posted a significant decrease in total hay and fodder crops in recent years (from 0.87 M ha in 1991 to 0.78 M ha in 2001). In comparison, total hay and fodder crops remained relatively constant in Ontario (at about 1 M ha) and increased in Atlantic Canada (from 0.19 M ha in 1991 to 0.22 M ha in 2001). Furthermore, there has been relatively little adoption of reduced tillage practices that have the potential to boost SOC levels (77% of cropland seeded with residue-incorporating intensive tillage in 2001, compared with 52% in Ontario). Although the downtrend in soil organic carbon is a matter of concern, the mean rate of SOC change in Quebec in 2001 does not differ greatly from that recorded for the rest of Eastern Canada (ON: -4 kg ha^{-1} yr^{-1}; QC: -18 kg ha^{-1} yr^{-1}; Atlantic: 3 kg ha^{-1} yr^{-1}).

■ RESPONSE OPTIONS

Maintaining soil organic carbon requires that a sufficient amount of organic residues be added to offset the carbon lost through decomposition and erosion. Reducing soil erosion is critical for maintaining or increasing SOC. Practices that can help to reduce soil erosion include reducing tillage, planting cover crops, strip cropping, tillage along contours, grassed waterways and water control structures, as well as reducing bare summerfallow.

Practices that can increase organic residues include the following: removing crop residues seldom or not at all; refraining from burning crop residues; applying manure or compost to soils (especially to soils that are degraded in SOC); reducing the amount of summerfallow; providing adequate crop fertilization; proper irrigation scheduling; rotating crops that produce little crop residue, such as potato, with crops that produce abundant crop residue, such as grains, growing cover crops and/or green manure crops; and maintaining good range and pasture conditions. Practices that help to lessen the decomposition of SOC include reducing tillage, growing perennial crops and reducing summerfallow.

■ REFERENCES

Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima, 1987. *Analysis of factors controlling soil organic matter levels in Great Plains grasslands.* Soil Science Society of America Journal. 51: 173-1179.

Parton, W.J., J.W.B. Stewart, C.V. Cole, 1988. *Dynamics of C, N, P and S in grassland soils: a model.* Biogeochemistry. 5: 109-131.

Shelton, I.J., G.J. Wall, J.-M. Cossette, R. Eilers, B. Grant, D. King, G. Padbury, H. Rees, J. Tajek, and L. van Vliet, 2000. *"Risk of water erosion"*. Pages 59-67 in Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project, Edited by T. McRae, C.A.S. Smith and L.J. Gregorich. Agriculture and Agri-Food Canada, Ottawa (Ont.). www.agr.gc.ca/env/naharp-pnarsa

Smith, W.N., P. Rochette, C. Monreal, R.L. Desjardins, E. Pattey, and A. Jaques, 1997. *The Rate of Carbon Change in Agricultural Soils in Canada at the Landscape Level.* Canadian Journal of Soil Science. 77 (2): 219-229.

Smith, W.N., G. Wall, R.L. Desjardins, and B. Grant, 2000. "Soil Organic Carbon". Pages 85-92 in Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project, Edited by T. McRae, C.A.S. Smith and L.J. Gregorich. Agriculture and Agri-Food Canada, Ottawa (Ont.). www.agr.gc.ca/env/naharp-pnarsa

Smith, W.N., R.L. Desjardins, and E. Pattey, 2000. *The Net Flux of Carbon From Agricultural Soils in Canada 1970–2010.* Global Change Biology. 6(5): 557-568.

15. Soil Salinity

AUTHORS:
B.H. Wiebe,
R.G. Eilers,
W.D. Eilers and
J.A. Brierley

INDICATOR NAME:
Risk of Soil Salinization

STATUS:
Provincial coverage (AB, SK, MB), 1981 to 2001

■ SUMMARY

At very low levels, some salts that are naturally present in soils are taken up by plants as nutrients. However, at higher levels, soluble salts can inhibit the ability of the plant roots to absorb both water and nutrients and thus restrict crop growth, resulting in lower yields. Some land use practices contribute substantially to soil salinization by affecting the quantity and the flow of water and salts through the root zone. The practice of summerfallow typically increases water content in the root zone, which can lead to an elevated water table and increasing levels of soluble salts at or near the soil surface. By contrast, permanent cover and continuous cropping are two practices that promote water use from the root zone, lower the water table and reduce the potential for salinization. The Risk of Soil Salinization Indicator (RSS) has been developed to assess changes in the risk of dryland *soil salinization in the Prairies as a function of changing land-use and management practices that influence the amount and movement of water and salts in the root zone.*

In 2001, almost 12% of the land area in the agricultural regions of the Prairies (8 million ha) was rated as having a moderate, high or very high risk of salinization. This represents a significant improvement from the 1981 value of 18%. The decline in the higher risk classes is balanced by an increase in the proportion of land presenting a very low risk of salinization, which went from 62% to 70% over the 20-year period studied. This improvement can largely be attributed to the reduction in summerfallow, which went from an area of 9.5 million hectares in 1981 to 4.6 million hectares by 2001, as farmers moved to implement continuous cropping. The area under permanent cover also increased but this change was less dramatic and had a smaller impact on the risk of soil salinization. Although the problem is far from eliminated, there is a trend towards greater soil health and agri-environmental sustainability, which is attributed to current land use and management practices, programs and policies.

■ THE ISSUE

Many prairie soils contain naturally high levels of water-soluble salts, including the sulphates of sodium, calcium and magnesium. At very low levels, some of these salts are used as nutrients by plants. However, as soluble salts accumulate in the plant root zone during the natural process called soil salinization, they can adversely affect plant growth. The effect of salinization on plants is similar to drought because as the concentration of dissolved salts increases, the ability of the plant roots to absorb both water and nutrients decreases. At high levels of salts, normal crop growth is restricted and yields are reduced. For example, moderate to severe soil salinity can reduce yields of most cereal and oilseed crops by at least 50%. Depending on the type of salts present, toxicity may result from boron, sodium and/or chloride in isolated cases.

The process of dryland soil salinization begins when water from excess precipitation in one part of the landscape moves down below the root zone, carrying dissolved salts to the water table. Groundwater flow then carries these dissolved salts to low-lying areas, where the water table is typically closer to the soil surface. The process ends in these locations when the water evaporates, leaving the salts behind, and they accumulate at or near the soil surface as white crusts or as crystalline precipitates in the soil profile.

Although a water deficit is the prime factor necessary for salinization to occur, several other factors help to control the process, most of them beyond human control: topography, inherent salt content of the soil parent material, the underlying geology and hydrology. Land use practices can also have a major impact on local hydrology, either exacerbating or mitigating soil salinization. A primary example is the practice of summerfallow, in which some land is maintained without actively growing plant cover during the growing season. The lack of plant cover allows more precipitation to be stored in the soil, sometimes causing the water table to rise. Permanent plant cover and continuous cropping are practices that help to keep excess soil water from becoming redistributed within the landscape, since the plant cover or crops absorb more of the water where it enters the soil, thereby reducing the risk of salinization occurring in other areas.

■ THE INDICATOR

The Risk of Soil Salinization Indicator has been developed to assess and track changes in the risk of soil salinization in the Prairies relative to changes in land use and management practices. The indicator does not measure the actual area of saline land or the area affected by an increase in the degree or extent of salinity. Instead, it evaluates the potential for increasing soil salinity that is associated with the agricultural land use patterns of the day. This indicator therefore reflects how the agricultural industry is performing with respect to the goals of sustainable agriculture, specifically the long-term impacts on quality of agricultural soils and adjacent non-agricultural soils.

The indicator results are expressed in five classes of risk for potential degradation of soil quality: very low (risk is negligible); low (risk is acceptable); moderate (awareness of the situation is important); high (heightened concern is warranted); and very high (immediate attention is likely required). The class limits were determined by first calculating assumed best and worst case scenarios and then subdividing the continuum to reflect relative levels of land use and management impacts. The map classes are based on weighted average risks for given land areas (polygons), and therefore the most sensitive portions will be at higher risk and the remainder at lower risk than indicated by the risk class. The performance objective for this indicator is to have an increasing portion of land in the very low and low risk classes.

■ CALCULATION METHOD

The Risk of Soil Salinization Indicator (RSS) is derived by calculating a salinity risk index (SRI) (Eilers et al. 1997). The SRI is used to rank individual land areas according to the relative risk of the areas becoming more saline under a given management program. The following factors are used in the calculation:

- Soil salinity status within the landscape, which is derived from a new soil salinity map showing the presence and extent of salinity in the agricultural regions of the Canadian Prairies; the map itself represents a compilation of information available from recent, detailed digital databases for each province, salinity surveys, published soil survey reports and provincial expert opinion.
- Topography and soil drainage classes were obtained from the Soil Landscapes of Canada (SLC) version 3.0 polygon component table for the provinces.
- Growing season climatic moisture deficits (May through August) were derived from the *ecodistrict* precipitation and potential *evapotranspiration* values calculated using the 1961-1990 30-year climate normals (Agriculture and Agri-Food Canada 1997).
- Land use data were obtained from the *Census of Agriculture* for the 1981, 1986, 1991, 1996 and 2001 Census years.

The first three factors were considered to remain constant over the time period covered by the analysis in order to isolate the impact of land use changes as determined from Census of Agriculture data. Land under summerfallow was considered to be at highest risk; land under permanent cover was associated with the lowest risk; and land under annual cropping was deemed to be at an intermediate risk level. Because the Census does not distinguish between annual and *perennial forage* crops (other than alfalfa and silage corn), the area of "other tame hay and fodder crops" was included as permanent cover for the purposes of this analysis.

An expert committee for soil salinity in the Prairies developed a weighting for the different factors to be used in calculating the SRI, based on the presumed influence of these factors on the process of soil salinization. The weighting of the land use factor was based on the percent of permanent cover in each SLC polygon, combined with the portion of annual cropland devoted to summerfallow. The SRI is the unitless multiplicative total of the individual factor values for each component soil. The values for the components within a polygon were then area-weighted to arrive at the SRI value for the polygon. The SRI values were grouped into five risk classes for the RSS Indicator, which were subsequently displayed on a map to spatially illustrate the change in risk from one Census year to the next.

■ LIMITATIONS

The indicator has been developed for rainfed/dryland regions and it does not evaluate the risk of salinization under irrigation. Irrigation affects local hydrology, changes the moisture deficit and introduces some salts in the irrigation water on a field-by-field basis, and therefore cannot be properly analyzed at this broad scale. Non-agricultural land uses (e.g. roads, ditches, traffic corridors) influence the flow of surface and subsurface water and therefore can affect soil salinization. They, too, are not currently reflected in this broad-scale analysis.

Another limitation of this analysis is that it only produces a snapshot of the conditions reported in each Census year and may not always properly reflect yearly trends and fluctuations. In order to isolate the impact of agricultural land use, long-term average climatic data were used in the analysis. Although annual variability in water deficits can have a significant effect on the risk of salinization, this is a topic that will have to be addressed in a future study. Regional groundwater flows can also have a major impact on soil salinization but they are covered only indirectly in the indicator, through the factor related to the current presence and extent of salinity.

> *The proportion of land at moderate to very high risk of salinization decreased across the Prairies between 1981 and 2001.*

Work continues with a view to further developing and refining the Risk of Soil Salinization Indicator. Data from the monitoring of long-term salinity benchmark sites will be used in modelling analyses of the components that control salinization processes and in sensitivity analyses. Emphasis will be placed on further evaluating the factor weightings and on validating the risk class limits. Although some land use practices may be lowering the risk of salinity, the increasing diversity of crops may signal a trend toward higher sensitivities or lower salinity threshold levels for optimum growth. Therefore, the current focus on moderately to severely saline soils may need to be reconsidered to include soils with lower levels of salinity.

■ RESULTS

Figure 15-1 shows the risk of soil salinization in relation to 2001 land use practices. The pattern generally reflects soil zonal boundaries, with the lower risk classes corresponding to the more humid Black Soil zone. The exception to this pattern is Manitoba, where lack of relief and poorer drainage in the soil landscapes of the south-central part of the province place it at an inherently higher risk of salinization.

The actual proportions of land in each of the five risk classes from 1981 to 2001 are presented in Table 15-1. The proportion of land at moderate to very high risk of salinization decreased across the Prairies between 1981 and 2001. The largest decrease was observed in the moderate risk class, which declined from 12% to 7%. As might be expected, this trend resulted in an increase in the very low risk class, which went from 62% to 70%.

Table 15-1: Share of agricultural and adjacent non-agricultural land in various soil salinization risk classes, 1981 to 2001

Share of Land in Different Classes (in %)

	Very Low					Low					Moderate					High					Very High				
	81	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**	**81**	**86**	**91**	**96**	**01**
AB	81	80	82	85	86	12	13	12	10	10	4	5	4	3	3	1	1	1	1	1	1	1	1	1	1
SK	45	49	48	53	58	30	28	29	28	28	17	16	15	12	8	2	3	3	2	3	6	5	5	5	4
MB	59	60	66	63	65	13	11	10	12	12	18	18	17	18	17	7	9	6	6	5	4	2	1	1	1
Prairies	**62**	**63**	**64**	**68**	**70**	**20**	**19**	**19**	**18**	**18**	**12**	**12**	**11**	**9**	**7**	**3**	**3**	**3**	**2**	**2**	**4**	**3**	**3**	**3**	**2**

Alberta: The RSS indicator showed a similar pattern to that for the Prairies as a whole, with an increase of 5% in the very low risk class. All other classes showed a decrease in area, but the main changes were a 2% decrease in the low risk class and a near 2% decrease in the moderate risk class. Of the three Prairie Provinces, Alberta had the largest area of land in the very low risk class.

Saskatchewan: The indicator showed the greatest improvement for this province since the portion of land in the very low risk class rose by 13%, reaching 58%. This improvement is linked mainly to the moderate class, which dropped from 17% to 8% between 1981 and 2001. Decreases were also seen in the very high risk class and the low risk class.

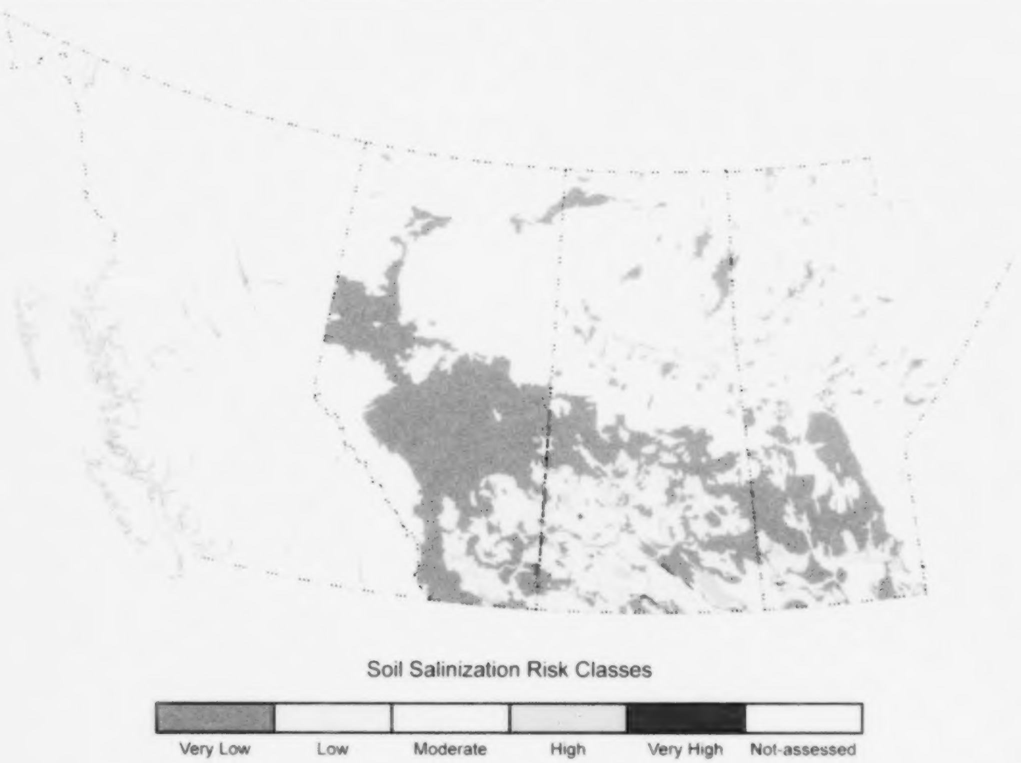
Manitoba: The indicator showed improvements in all classes between 1981 and 2001, with the most noteworthy ones being an increase in the amount of land rated in the very low risk class (from 59% to 65%) and a decrease in the amount rated in the very high risk class (from 4% to 1%). Unlike the other provinces, which exhibited fairly gradual changes throughout the period, most of the change in Manitoba occurred before 1991.

■ INTERPRETATION

The overall analysis using the RSS indicator identified a trend of declining risk of soil salinization owing to changes in land use practices over time (accepting the assumption that all other variables were constant over the time period studied).

The Prairie-wide increase in the area of land in the very low risk class between 1981 and 2001 can largely be attributed to the steady decline in summerfallow over the same time period (see Chapter 6). In addition, the area of permanent cover, which can significantly lower the risk of soil salinization, fluctuated somewhat during those years and showed a small overall net increase of 1.7 million hectares.

Figure 15-1: Risk of Soil Salinization in the Prairie Region under 2001 agricultural land use practices



Alberta: The decrease in risk level across much of the agricultural region paralleled the steady decrease in summerfallow area between 1981 and 2001, as farmers gradually moved to continuous cropping, even in the Brown Soil Zone. Changes in permanent cover did not have a detectable impact on the risk of salinization except for a few areas in the southern and eastern regions of the province, where the situation improved due to both a decrease in summerfallow and an increase in permanent cover.

Saskatchewan: The steady decrease in salinization risk observed in Saskatchewan was mirrored by an analogous trend in the use of summerfallow. Summerfallow decreased in almost all of the agricultural regions of the province, with the exception of some areas in the west and southwest.

Manitoba: A decrease in risk of salinization also occurred in Manitoba, but a different pattern is seen than in the other two Prairie Provinces. The area in each risk class remained fairly constant from one Census year to the next, except for a significant decrease in risk between 1986 and 1991 coinciding with a 40% reduction in summerfallow area. Despite several drier than normal years, reductions in summerfallow between 1986 and 1991 apparently reflected a continuation of an earlier trend that was likely driven by a greater than three-fold increase in the price of wheat between 1971 and 1981 (Manitoba 2004). Although the area of permanent cover did increase across the province, mostly between 1996 and 2001, this change was not accompanied by a similar decrease in salinization risk. The south-central region of the province showed little change in land use and hence little change in salinization risk.

■ RESPONSE OPTIONS

Beneficial management practices that producers can use to reduce the risk of dryland salinization focus on soil-water management. The majority of these involve land use changes designed to increase the use of precipitation where it falls and hence reduce the movement of excess water (and leaching of salts) through the soil to the water table. Where high water tables are already a concern, increased water extraction from the subsoil by deep-rooted plants tends to reduce surface evaporation of water and therefore salinization. Land and water management practices that help to reduce the risk of dryland salinization include reducing summerfallow; increasing the area of perennial forages, pasture and tree crops; increasing *minimum tillage* or no-till; including more salt-tolerant crops in rotations in regions affected by soil salinity; planting deep-rooting perennial crops in places where excess moisture is causing salinization; using inputs such as mineral fertilizer and animal manures more effectively; using appropriate surface drainage; installing interceptor forage strips or strategic subsurface tile (plastic) drainage; managing snow to prevent deep snowdrifts which can cause localized excess moisture; using new technologies such as precision farming; and monitoring groundwater depth in sensitive areas as an aid in selecting crop rotations.

■ REFERENCES

Agriculture and Agri-Food Canada, 1997. *Canadian Ecodistrict Climate Normals 1961-1990.* http://sis.agr.gc.ca/cansis/nsdb/ecostrat/district/climate.html

Eilers, R.G., W.D. Eilers, and M.M. Fitzgerald, 1997. *A Salinity Risk Index for Soils of the Canadian Prairies*. Hydrogeology Journal. 5 (1): 68-79.

Manitoba Agriculture, Food and Rural Initiatives, 2004. *Manitoba Agriculture Yearbook 2002, 39th ed.* Manitoba Agriculture, Food and Rural Initiatives, Program and Policy Analysis Branch, Winnipeg (Man.).

16. Trace Elements

■ SUMMARY

Some trace elements *that occur naturally in soils can, as a result of specific conditions and activities, accumulate to levels of concern for crop quality, productivity or human health. On agricultural land, this situation can be exacerbated by trace elements from agricultural inputs (fertilizers, manures, irrigation water). An Indicator of Risk of Soil Contamination by Trace Elements is currently being developed to gain a better understanding of how various agricultural management practices can affect the levels of trace elements in the soil and change their* bioavailability. *The indicator will likely take the form of element balances, with soil inputs and losses being calculated and adjusted based on a set of parameters that influence trace element availability (solubility of input source, soil-related factors, cropping system parameters). Producers can use various beneficial management practices to mitigate the risk and improve environmental performance in relation to the trace element indicator. These consist primarily in limiting inputs, increasing off-take (removal from the soil) or reducing bioavailability.*

AUTHORS:

C.A. Grant,
S.C. Sheppard,
M.I. Sheppard
and J.C. Tait

INDICATOR NAME:

Risk of Soil Contamination by Trace Elements

STATUS:

Currently under development

■ THE ISSUE

Trace elements can be grouped into two broad categories: those that are considered essential for plant growth and those that are not. Both essential and non-essential trace elements can be further grouped in risk categories, based on their potential for building up to levels of concern through agricultural activities (see Table 16-1). A higher risk implies a greater possibility that acceptable concentrations will be exceeded at some time in the future. In this study, emphasis will initially be placed on trace elements in the high risk category.

Many trace elements are naturally present in the soil at various levels, and all land in Canada continuously receives trace elements from dust and from *atmospheric wash-out* (industrial contamination). On agricultural land, however, these sources may be augmented by trace elements from agricultural inputs such as fertilizers, manures, *biosolids* (e.g. municipal sludge) and irrigation water. When present in the soil in sufficient quantities, some trace elements can reduce crop quality, impair productivity and even move up the food chain through plants, creating health concerns for livestock and humans. It is therefore important to estimate the risks of short- and long-term impacts resulting from the small inputs of trace elements that are routinely used in agricultural systems, and to understand how soil management practices can affect the levels of trace elements and change their bioavailability.

Policies have been put in place to regulate the trace elements in the fertilizers, biosolids and municipal effluents that are used in agriculture. For the most part, Canadian agricultural soils have not been significantly enriched in trace elements through *anthropogenic* (human) activities. This situation may change in the future, however, as livestock production expands, fertilizer applications increase and the spreading of biosolids and effluents on agricultural soils becomes a more common practice.

Table 16-1: Selected trace elements and their potential to accumulate at levels of concern through agricultural activities

	Risk Category		
	Low	**Moderate**	**High**
Essential trace elements	Iron Manganese Nickel	Copper	Selenium Boron
Non-essential trace elements	Chromium	Arsenic	Cadmium Mercury Lead Thallium

THE INDICATOR

An Indicator of Risk of Soil Contamination by Trace Elements is currently being developed to provide a means of estimating the accumulation of trace elements in agricultural soils. Among other attributes, this indicator will have the capacity to:

- estimate inputs to all major agricultural resources across Canada;
- be responsive to management measures that are initiated to control inputs;
- account for toxic or health effect thresholds;
- account for the cumulative effects of multiple contaminants;
- be sensitive to various soil conditions that influence the bioavailability of trace elements;
- accommodate all Canadian climatic conditions.

The indicator will calculate a balance for individual trace elements by considering soil inputs and losses, and it will integrate both temporal and spatial aspects. The model used will also allow an over-all indicator to be calculated for all the trace elements combined, and it will take background (natural) concentrations of the trace elements into account. These calculations will be done for a series of Soil Landscape of Canada (SLC) units. The "picture" that is obtained will nonetheless include the potential impact of "hot spots," or small areas where the risk level is higher than for the summarized SLC situation. When the model is ready, it will be applied to a region on a pilot basis to evaluate the proposed methodology before it is used at the national scale. Information will be obtained to determine the critical load of these trace elements such as done for smelter emissions by Doyle et al. (2003). These critical loads could be based, for example, on CCME (Canadian Council of Ministers of the Environment) guidelines (CCME 2002).

When present in the soil in sufficient quantities, some trace elements can reduce crop quality, impair productivity and even move up the food chain.

CALCULATION METHOD

The Indicator of Risk of Soil Contamination by Trace Elements will be calculated using a mathematical model that will determine trace element availability, based on net accumulation, relevant soil characteristics and management factors. The net accumulation of trace elements from agricultural activity will be determined using a total input minus total loss approach. The net accumulation information will then be adjusted to account for a series of parameters that influence trace element availability, such as the solubility of the input source; soil-related factors (e.g. pH, organic matter content); environmental factors (e.g. climate); cropping system parameters (e.g. tillage system, nutrient rate, crop selection and rotation) (Sheppard and Sheppard, 2004). The data needed to compute the indicator have been reviewed. In general, the indicator will harness georeferenced soil data to create a base map that will be layered with the trace element information. However, the information about trace element inputs is not georeferenced in sufficient detail at present.

In toxicity assessment, multiple contaminants are typically present and they can interact with one another. A conceptual model has been developed that sums up the risk of impacts associated with a variety of trace elements from multiple sources. This will allow the indicator to be reported as a single quantity (as opposed to having a separate quantity for each trace element). This single quantity may be expressed as the relative proportions of agricultural land that fall in defined risk categories, representing the risk of eventually exceeding acceptable soil concentrations of trace elements.

LIMITATIONS

Although creating the Indicator of Risk of Soil Contamination by Trace Elements is a feasible task, and one that involves drawing on related indicators described in the literature, there are a number of factors pertaining to both the model itself and the input data that may limit the indicator results.

- There is likely to be a large degree of spatial variability in the inputs that will need to be addressed to account for the impact on soil areas near urban centres and to be able to identify "hot spots" within these defined areas. A method will have to be developed to account for the fact that, for example, some farms may accept urban biosolids but adjacent farms may not.
- The CCME guidelines (CCME 2002) do not sufficiently reflect soil properties, and one challenge facing us will be to derive acceptable upper-limit soil concentrations that are a function of soil properties.
- Since there is no simple and inclusive method for assessing the impact of multiple contaminants, several approaches may need to be considered.
- There is no central registry to track inputs from soil amendments such as biosolids, so inputs will have to be estimated from regional averages and statistical characteristics.
- Biosolids and wastewater quality and characteristics vary among the provinces and municipalities, and records of these have only begun to be maintained recently.
- Information on the levels of trace elements in feed supplements belongs to the feed manufacturers; and so a method will have to be developed to calculate a probable range of values.

■ RESULTS

This indicator is currently under development and results are not yet available.

■ RESPONSE OPTIONS

There are some beneficial management practices that producers can implement to mitigate risk and improve environmental performance in relation to the trace element indicator. These consist mainly in limiting inputs, increasing off-take or reducing bioavailability. Limiting contaminant inputs at source is certainly the overriding mitigation factor, particularly in areas where the bioavailability of added trace elements is likely to be high. This can be achieved by controlling trace element levels in feed and fertilizer sources, reducing these inputs through improved nutrient use efficiency and reducing trace elements in biosolids or manure used for land application.

Beneficial management practices that can increase off-take include promoting optimum crop yields and *bioremediation* based on removing crop residues from accumulator crops and using them in non-food systems (ethanol production, straw board, flax fibre uses), to prevent the transfer of trace elements to the food chain. Finally, practices that can reduce bioavailability include targeted nitrogen application rates (as nitrogen can increase the solubility of some trace elements), fertilizer source (as the source can influence the bioavailability of trace elements), crop sequencing, optimizing micronutrients, *pH* modification in acid soils, organic matter manipulation, crop and cultivar selection and avoiding the addition of chloride in irrigation water (Grant et al. 1999).

■ REFERENCES

CCME (Canadian Council of Ministers of the Environment) and the National Guidelines and Standards Office (NGSO), 2002. *Canadian Environmental Quality Guidelines*. Environment Canada, NGSO, Ottawa (Ont.). www.ec.gc.ca/CEQG-RCQE/ English/default.cfm

Doyle, P. J., D.W. Gutzman, M.I. Sheppard, S.C. Sheppard, G.A. Bird, and D. Hrebenyk, 2003. *An Ecological Risk Assessment of Air Emissions of Trace Metals From Copper And Zinc Production Facilities*. Human and Ecological Risk Assessment. 9 (2): 607-636.

Grant, C.A., L.D. Bailey, M.J. McLaughlin and B.R. Singh, 1999. *"Management Factors Which Influence Cadmium Concentrations in Crops"*. Pages 151-198 in Cadmium in Soils and Plants, McLaughlin M.J. and B.R. Singh (eds). Kluwer Academic Publishers, Dordrecht (Netherlands).

Sheppard, S.C. and M.I. Sheppard, 2004. *Trace Element Contamination – NAHARP Scoping Paper*. Agriculture and Agri-Food Canada, NAHARP (National Agri-Environmental Health Analysis and Reporting Program), Ottawa (Ont.).

Water Quality

D

17. Nitrogen

AUTHORS:
R. De Jong,
J.Y. Yang,
C.F. Drury,
E. Huffman,
V. Kirkwood and
X.M. Yang

INDICATOR NAME:
Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N)

STATUS:
National coverage, 1981 to 2001

SUMMARY

Increasing amounts of nitrogen are being added to crops in the form of fertilizer and manure to optimize yields and, more broadly, to meet the growing demand for food and fibre. An agri-environmental indicator—the Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N)—has been developed to assess the risk of nitrogen moving from treated agricultural areas into nearby surface water bodies, where the nitrogen can contribute to algae growth and eutrophication or into groundwater where it can reduce drinking water quality. This indicator links the output from the Residual Soil Nitrogen (RSN) Indicator to climatic conditions in order to assess the likelihood that nitrogen will move out of the agricultural system and into the surrounding environment. The results are assessed in terms of nitrate lost through leaching and nitrate concentration in the leached water. Risk of water contamination may arise when unduly large surpluses of nitrogen are present in the soil at the end of the growing season, especially in humid regions.

The overall nitrate loss for Canada increased by 25% from 6.1 kg of nitrate per hectare in 1981 to 7.6 kg of nitrate per hectare in 2001. Similarly, the overall nitrate concentration in water was 24% higher in 2001 (7.3 mg of nitrate per L) than in 1981 (5.9 mg of nitrate per L). The proportion of farmland in the combined low and very low IROWC-N risk classes decreased from 81% in 1981 to 65% in 2001. This trend was paralleled by an increase in the area of land falling into the higher risk classes. Increases in nitrogen fertilizer use (e.g. on the Prairies), increases in livestock numbers in the Atlantic Provinces and an increase in legume crop acreages in Central Canada are some of the factors that contributed to the increase in both nitrate concentrations and losses. Climatic factors also come into play, as evidenced by the effect that low precipitation levels reduced yields and nitrogen uptake in many regions of Canada in 2001.

THE ISSUE

Nitrogen (N) is an essential nutrient required by all crops. Legumes (e.g. soybean, alfalfa) fix nitrogen from the atmosphere, but non-leguminous crops (e.g. corn, cereal crops, potatoes) require applied nitrogen for optimal growth and yield (Drury and Tan 1995). Increasing levels of nitrogen are being added to these non-leguminous crops through fertilizer and manure use as the agricultural sector strives to meet the increasing demand for food and fibre.

The addition of nitrogen is not always without risks, however. Some nitrogen may eventually move from treated agricultural areas into the broader environment, notably into water resources. Nitrogen losses to the environment occur because not all of the applied nitrogen is used by the crop, and some residual nitrogen inevitably remains in the soil at the end of the growing season (see Chapter 9). Risk of water contamination may arise when unduly large surpluses of nitrogen are present in the soil under humid conditions. Most of the residual inorganic nitrogen, which is in the form of nitrate, is water-soluble and is susceptible to leaching through the soil into groundwater or flowing through tile drainage and eventually entering ditches, streams and lakes. High nitrate levels in surface waters can contribute to algae growth and eutrophication, and in cases where drinking water is affected, there may be human health implications (Chambers et al. 2001).

THE INDICATOR

The Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N) has been developed to link the quantity of mineral N remaining in the soil at harvest (residual soil nitrogen) with climatic conditions in order to assess the likelihood that nitrogen, in the form of nitrate, will leach out of agroecosystems (MacDonald 2000).

A simplified conceptual view of the nitrogen flow in agroecosystems illustrates the biophysical principles behind this indicator (Figure 17-1).

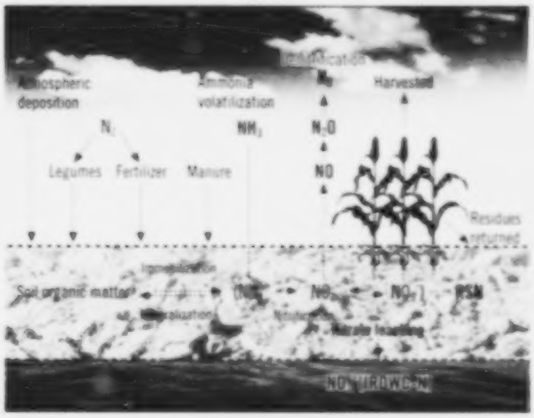
Table 17-1: IROWC-N risk classes, based on nitrate- N concentration in water and total amount of nitrate lost

		Nitrate Lost (kg of N / ha)			
		0-4.9	5.0-9.9	10.0-19.9	≥20
Nitrate Concentration	0-4.9	Very Low	Very Low	Low	Moderate
(mg of N / L)	5.0-9.9	Very Low	Low	Moderate	High
	≥10	Low	Moderate	High	[illegible]

The annual net gain of nitrogen, called residual soil nitrogen (RSN), is the difference between N inputs and N outputs. Inputs consist of atmospheric deposition, fixation by leguminous plants and N additions to farmland in fertilizer and manure. The outputs from the system include N lost in gaseous form to the atmosphere (denitrification and ammonia volatilization), N removal in plant material taken from the field and N leached into groundwater and/or surface water (for additional details concerning the methods and assumptions for calculating RSN see Chapter 9). This last component (N leaching) is what the IROWC-N indicator attempts to capture.

The IROWC-N indicator is expressed as the proportion of agricultural land that falls into each of five risk classes (see Table 17-1). These classes are derived by linking two components: (i) four levels of soil nitrogen leaching out of the soil profile during the non-growing (winter) season (N_{lost}, or nitrate lost, expressed in kg of N per hectare); and (ii) three levels of nitrate concentration in the leached water (N_{conc}, or nitrate concentration, expressed in mg of N per L). The latter element can be related to the Canadian drinking water guideline of 10 mg of NO_3-N per L. These two factors are used in classifying IROWC-N because they both ultimately influence the potential environmental impacts of nitrogen loss. For example, with high volumes of drainage water and high nitrogen losses, the nitrate concentration may be fairly low owing to dilution, and the environmental impacts would not be as severe as in a situation with high losses and high nitrate concentrations. The performance objective for this indicator is to have increasing amounts of agricultural land in the low risk classes (Classes 1 and 2).

Figure 17-1: Conceptual view of N flows in an agroecosystem



■ CALCULATION METHOD

The IROWC-N indicator was calculated at the Soil Landscape of Canada (SLC) level by combining residual soil nitrogen values (estimated from the difference between N inputs and N outputs), obtained using the standardized Canadian Agricultural Nitrogen Budget (CANB Version 2.0, see Chapter 9), with weather and soil data, in order to calculate N_{lost} and N_{conc}. A water balance model was used to estimate the daily water surplus during the non-growing season (from September 1 to March 31), when most of the potential nitrate loss occurs. The water balance model considers daily precipitation (P) and potential evapotranspiration (PE) as well as the available water-holding capacity of soils (AWHC). N_{lost} and N_{conc} calculations were made for each year (1979 to 2003), and averages of the four winter periods centered around Census years

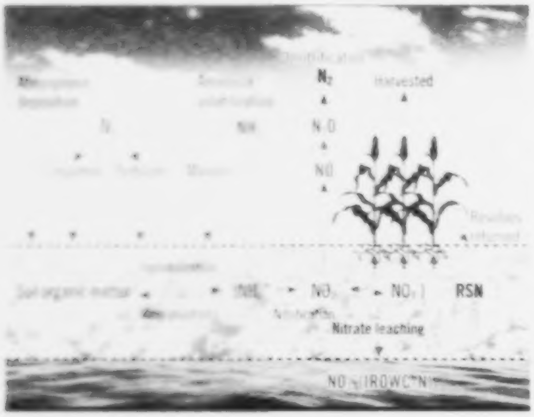
Table 17-1: IROWC-N risk classes, based on nitrate- N concentration in water and total amount of nitrate lost

		Nitrate Lost (kg of N / ha)			
		0-4.9	5.0-9.9	10.0-19.9	>20
Nitrate Concentration	0-4.9	Very Low	Very Low	Low	Moderate
(mg of N / L)	5.0-9.9	Very Low	Low	Moderate	High
	>10	Low	Moderate	High	Very High

The annual net gain of nitrogen, called residual soil nitrogen (RSN), is the difference between N inputs and N outputs. Inputs consist of atmospheric deposition, fixation by leguminous plants and N additions to farmland in fertilizer and manure. The outputs from the system include N lost in gaseous form to the atmosphere (denitrification and ammonia volatilization), N removal in plant material taken from the field and N leached into groundwater and/or surface water (for additional details concerning the methods and assumptions for calculating RSN see Chapter 9). This last component (N leaching) is what the IROWC-N indicator attempts to capture.

The IROWC-N indicator is expressed as the proportion of agricultural land that falls into each of five risk classes (see Table 17-1). These classes are derived by linking two components: (i) four levels of soil nitrogen leaching out of the soil profile during the non-growing (winter) season (N_{lost}, or nitrate lost, expressed in kg of N per hectare); and (ii) three levels of nitrate concentration in the leached water (N_{conc}, or nitrate concentration, expressed in mg of N per L). The latter element can be related to the Canadian drinking water guideline of 10 mg of NO_3-N per L. These two factors are used in classifying IROWC-N because they both ultimately influence the potential environmental impacts of nitrogen loss. For example, with high volumes of drainage water and high nitrogen losses, the nitrate concentration may be fairly low owing to dilution, and the environmental impacts would not be as severe as in a situation with high losses and high nitrate concentrations. The performance objective for this indicator is to have increasing amounts of agricultural land in the low risk classes (Classes 1 and 2).

Figure 17-1: Conceptual view of N flows in an agroecosystem



■ CALCULATION METHOD

The IROWC-N indicator was calculated at the Soil Landscape of Canada (SLC) level by combining residual soil nitrogen values (estimated from the difference between N inputs and N outputs), obtained using the standardized Canadian Agricultural Nitrogen Budget (CANB Version 2.0, see Chapter 9), with weather and soil data, in order to calculate N_{lost} and N_{conc}. A water balance model was used to estimate the daily water surplus during the non-growing season (from September 1 to March 31), when most of the potential nitrate loss occurs. The water balance model considers daily precipitation (P) and potential evapotranspiration (PE) as well as the available water-holding capacity of soils (AWHC). N_{lost} and N_{conc} calculations were made for each year (1979 to 2003), and averages of the four winter periods centered around Census years were calculated for each Census year covered in this report (1981, 1986, 1991, 1996 and 2001). Results were then mapped using the criteria described in Table 17-1.

The required weather data, including daily maximum and minimum air temperatures and daily precipitation for the period 1979 to 2003, were obtained from Agriculture and Agri-Food Canada's ecodistrict climate databases. Daily potential evapotranspiration was calculated using the Baier and Robertson (1965) technique. Soil available water-holding capacity (AWHC) was calculated for each SLC polygon, based on the AWHC values for the component soils and their percent distribution within the SLC polygon, obtained from the Canada Soil Information System (CanSIS).

LIMITATIONS

Calculation of this indicator was subject to the same limitations as those described for the RSN Indicator (Chapter 9). The procedure used to calculate water surplus (P – PE) would typically underestimate its true value because potential evapotranspiration is always greater than actual evapotranspiration. Thus nitrate concentrations would be overestimated because with predicting a lower water surplus there would be less dilution. The N loss would be underestimated, as the lower soil water surplus would result in less water and nitrate draining from the land. The water balance was calculated for the entire over-winter period, and hence the methodology does not capture the effects of individual storms and run-off events occurring at various times of the year. Finally, some AWHC values and weather data were not available for certain SLC polygons, which meant that generic assumptions had to be made to permit calculation (e.g. use of weather data from adjacent regions or from the closest polygon).

> *Most of the farmland in Canada fell into the very low and low risk classes in each of the Census years between 1981 and 2001.*

Further work is required in order to improve the water balance component of IROWC-N and to evaluate not only over-winter losses of N but also growing season losses. A full accounting of the water balance, including the effects of major storms on surface run-off, is required for the entire year.

RESULTS

Results related to the proportion of farmland in each risk class are provided for the provinces and for Canada as a whole in Table 17-2. Figure 17-2 shows the geographical distribution of the farmland in the five IROWC-N classes in 2001. Readers should refer to Table 17-1 for details on the IROWC-N classes.

Canada: Most of the farmland in Canada fell into the very low and low risk classes in each of the Census years between 1981 and 2001. However, there was a marked decrease between 1981, when 81% of farmland was grouped in these two categories (65% and 16% respectively), and 2001, when 65% of farmland was in the very low (50%) and low (15%) risk classes. This trend was paralleled by an increase in the moderate (from 7% to 17%) and high risk classes (from 11% to 15%) during the same period. Less than 3% of the farmland fell into the very high risk class during any of the Census years investigated.

British Columbia: Similar to the national trend, a majority (51%) of farmland was in the very low (32%) and low (19%) risk classes in 2001, down from the 1981 value of 62% (44% in very low and 18% in low). During this 20-year period, the area of farmland in the moderate and very high risk classes increased by 6% and 2% respectively. Note that approximately 20% of the farmland in British Columbia was excluded from the calculations due to missing weather data.

Prairies: There was a general decrease in the proportion of farmland in the very low and low risk classes for all three Prairie Provinces between 1981 and 2001 (Alberta: from 97% to 87%; Saskatchewan: from 95% to 79%; Manitoba: from 12% to 4%). This trend was matched by a corresponding increase in the moderate risk class (Alberta: +11%, Saskatchewan: +13%; Manitoba: +18%). It is noteworthy that, in 2001, the area of farmland in the high and very high risk classes was 0% in Alberta and 3% in Saskatchewan. Of the three Prairie Provinces, Manitoba had the highest proportion of land in the high and very high

Table 17-2: Share of farmland in various IROWC-N classes, 1981 to 2001

Share of Farmland in Different Risk Classes (in %)

Province	Very Low					Low					Moderate					High					Very High				
	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01
BC*	44	47	42	38	32	18	14	18	16	19	10	15	14	15	16	7	2	3	4	7	2	4	4	6	4
AB	90	96	87	78	69	7	4	9	16	18	2	0	4	6	13	0	0	0	0	0	0	0	0	0	0
SK	80	70	72	67	64	15	23	16	24	15	5	3	10	6	18	0	4	2	2	3	0	0	0	0	0
MB	2	6	0	1	0	10	8	9	3	4	10	13	24	19	28	73	67	65	67	66	5	6	2	10	3
ON	13	30	14	9	2	47	70	72	60	7	26	0	9	19	11	14	0	5	12	73	0	0	0	1	8
QC	38	8	15	46	14	42	51	56	36	49	6	16	11	2	18	9	17	12	9	13	5	8	6	8	7
NB	1	0	0	2	1	54	2	3	29	24	25	2	29	33	17	20	63	60	24	45	1	34	9	11	14
NS	25	0	0	57	2	55	2	31	11	8	7	59	45	9	55	11	28	12	13	21	3	11	12	9	15
PEI	0	0	0	11	0	59	56	0	48	0	41	27	69	41	33	0	17	31	0	67	0	0	0	0	0
NL	38	0	26	16	5	11	8	6	5	25	14	3	26	12	20	21	36	14	7	19	17	52	28	61	31
Canada	**65**	**64**	**60**	**57**	**50**	**16**	**19**	**18**	**22**	**15**	**7**	**4**	**10**	**9**	**17**	**11**	**11**	**10**	**10**	**15**	**1**	**1**	**1**	**2**	**1**

* In British Columbia, the proportion of farmland in the five risk classes does not add up to 100% because some polygons were excluded from calculation due to missing weather data.

risk classes, or 66% and 3% respectively in 2001, down 9% from the 1981 levels.

Ontario: Whereas the percentage of farmland area in the very low and low risk classes was consistently over 60% for each Census year between 1981 and 1996, in 2001 there was a dramatic decrease with less than 10% of farmland falling into these two classes. This was accompanied by a significant increase in farmland in the high (14% in 1981 vs 73% in 2001) and very high (0% in 1981 vs 8% in 2001) risk classes.

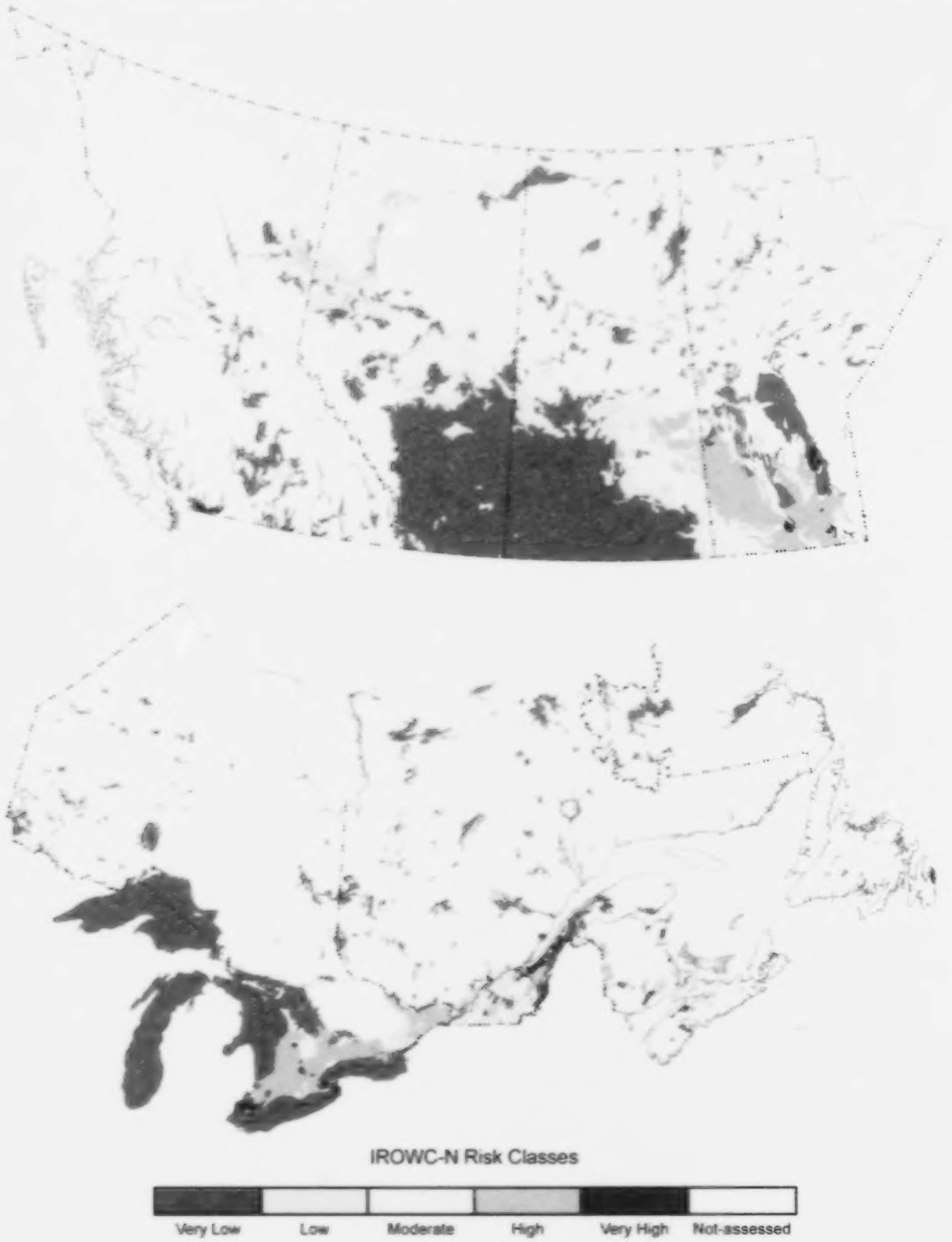
Quebec: Similar to the national trend, the majority (63%) of farmland fell into the very low (14%) and low (49%) risk classes in 2001, down from the 1981 value of 80% (38% in very low and 42% in low). During this 20-year period, the area of farmland in the moderate and high risk classes increased (+12% and +4% respectively). The very high risk class showed some fluctuations over the years but little overall change from 1981 to 2001 (+2%).

Atlantic: The majority of farmland in the Atlantic Provinces (except for Newfoundland and Labrador) fell into either the very low or low risk classes in 1981 (New Brunswick: 55%, Nova Scotia: 80%, Prince Edward Island: 59%) whereas slightly less than one-half of the farmland in Newfoundland and Labrador (49%) fell into these classes. The corresponding proportion was significantly lower in 2001 (New Brunswick: 25%, Nova Scotia: 10%, Prince Edward Island: 0%, Newfoundland and Labrador: 30%). This reflected an increasing shift toward the high and very high risk classes during the same period for all four provinces (New Brunswick: +38%, Nova Scotia: +22%, Prince Edward Island: +67%, Newfoundland and Labrador: +12%).

■ INTERPRETATION

Canada: The national decrease in the proportion of farmland in the very low and low risk classes can be interpreted by looking at the trends for the two components of the IROWC-N indicator: nitrogen concentration (N_{conc}) and nitrogen loss (N_{lost}). These were calculated using the RSN values, soil AWHC values and over-winter precipitation surplus values. Nationally, the values for N_{conc} remained fairly constant during the 1981 to 1996 Census years (4.9 mg of N per L in 1986 to 6.0 mg of N per L in 1991); however, the values increased by a substantial 28% over the 1996 level, reaching 7.3 mg of N per L in 2001. This increase was due in part to the higher RSN levels in 2001 (resulting from a combination of increased inputs—biological fixation and fertilizer and

Figure 17-2: Risk of Water Contamination by Nitrogen on farmland in Canada under 2001 management practices


IROWC-N Risk Classes
Very Low
Low
Moderate
High
Very High
Not-assessed

manure N additions—and lower outputs owing to reduced crop yields), coupled with a decrease in the over-winter precipitation surplus in 2001. N_{conc} values were always below 10 mg of N per L in all provinces, except Manitoba and Newfoundland and Labrador. Between 1981 and 2001, nitrogen losses through leaching were less than 50 kg of N per hectare in all provinces, except for Nova Scotia in 2001 (50.2 kg of N per ha) and Newfoundland and Labrador from 1986 to 2001 (67.1 to 121.6 kg N per ha). In contrast to Newfoundland and Labrador with its high losses, Alberta and Saskatchewan—together accounting for 70% of the total farmland area in Canada—had very low N losses (i.e. < 5 kg of N per ha), because of the small over-winter precipitation surplus and the slightly higher soil AWHC.

British Columbia: The increase in farmland area in the moderate and high risk classes can be attributed to an increase in the N_{conc} values, which reached 9.1 mg of N per L in 2001. N_{lost} increased steadily to a high of 27.5 kg of N per hectare in 2001. These trends can in turn be explained by high nitrogen fertilizer sales and high values of available manure-N, particularly in areas on southeastern Vancouver Island and in the Lower Mainland. Furthermore, the RSN values were higher and over-winter precipitation surplus values were lower in 2001.

Alberta: N_{conc} values were low (between 2.7 and 5.6 mg of N per L) because the corresponding RSN values were low. Similarly, N losses were low (below 5 kg of N per ha) during each of the Census years, as the over-winter precipitation surplus was low. In southern Alberta, there was an over-winter precipitation deficit, resulting in no N leaching at all.

Saskatchewan: This province had slightly higher RSN values than Alberta, but because the over-winter precipitation surplus was generally lower, N_{lost} and IROWC-N values were similar to those in Alberta. The highest risk areas were in the Black soil zone, where annual N fertilizer sales ranged from 15 to 75 kg of N per ha, a higher level than in the rest of the province.

Manitoba: Manitoba had the highest nitrate concentrations (11.8 to 15.5 mg of N per L) and the greatest N losses (11.9 to 15.7 kg of N per ha) of all the Prairie Provinces. This was caused primarily by much higher RSN values (at least 50% higher than in Alberta or Saskatchewan), giving rise to 2.5 times higher N_{conc} and 4 times higher N losses. Nitrogen concentrations (N_{conc}) were consistently above the 10 mg of N per litre reference level (drinking water guideline used in Canada) during the 20-year period. Figure 17-2 shows that, in 2001, the high risk and very high risk classes occurred in the Lake of the Woods, Interlake Plain and Lake Manitoba Plain regions.

Ontario: Compared to Manitoba, Ontario showed higher N_{lost} (12.4 to 28.6 kg of N per ha) but lower N_{conc} (2.7 to 6.6 mg of N per L), a situation that relates to the differing climatic conditions. In Ontario, a greater over-winter precipitation surplus contributes to more N loss in drainage water, but the greater precipitation also results in increased dilution. N_{conc} values in Ontario increased in 2001 to 6.6 mg of N per L, as did the N_{lost} values (28.6 kg of N per ha) as compared to the values in 1996 (4.2 mg of N per L and 17.9 kg of N per ha). Figure 17-2 shows that in 2001 some regions of southwestern Ontario fell into the very high risk class. In the Lake Erie Lowlands region, available manure-N was high, causing large areas of this region to fall into the very high risk class.

Quebec: Provincial averages of N_{conc} values were consistently below 6 mg of N per L throughout the study period, and N_{lost} values ranged from 17.7 to 26.5 kg of N per hectare. However, localized high risk areas are evident on the 2001 IROWC-N map (Figure 17-2). The three regions showing the highest N_{lost} and N_{conc} values were the Southern Laurentians, the Appalachians and the St. Lawrence Lowlands. The high values were mainly caused by high livestock populations and available manure-N.

New Brunswick: N_{conc} values were below 7.5 mg of N per L in all years except 1986, when the value reached the reference level of 10 mg of N per L. N_{lost} values ranged between 24.1 and 41.5 kg of N per hectare. The RSN values were approximately 50% higher than in Quebec, but nitrogen leaching (N_{lost}) was 63%

higher than in Quebec, primarily because of the higher over-winter precipitation surpluses and the lower soil AWHC values. As in the case of Quebec, Figure 17-2 shows that the highest risk areas are in the high livestock density areas of New Brunswick: the Uplands, the Maritime Lowlands and the Bay of Fundy coastal regions.

Nova Scotia: RSN, N_{lost} and N_{conc} values all increased considerably between 1996 and 2001, mainly as a result of higher N inputs and lower crop yields. The highest N_{conc} and N_{lost} occurred in 2001 (7.2 mg of N per L and 50.2 kg of N per ha). The average AWHC of the soils in Nova Scotia is low, because the soils are sandy and therefore vulnerable to nitrogen losses through leaching. The very high risk classes of IROWC-N were located in the Southern Nova Scotia Uplands, the Nova Scotia Highlands and the Annapolis-Minas Lowlands.

Prince Edward Island: This province showed higher RSN, N_{lost} and N_{conc} values in 2001 as compared to 1996, a performance very similar to that of Nova Scotia. The 2001 N_{lost} value (34.1 kg of N per ha) was twice as high as in 1996 (17.3 kg of N per ha). This can be attributed to slightly higher inputs and lower outputs of the RSN balance. N_{conc} values were below 6 mg of N per L during the 20-year period.

Newfoundland and Labrador: Newfoundland's RSN values were by far the highest in the country, and since the over-winter precipitation surplus was also the highest (> 720 mm), N losses were much higher than in other provinces (35.9 to 122 kg of N per ha). Although nitrate concentrations were high (4.5 to 17.4 mg of N per L), these were diluted by the large over-winter precipitation surpluses. It would seem that the amount of manure produced is excessive relative to the land area available for spreading it.

■ RESPONSE OPTIONS

Since neither AWHC values nor weather variables (precipitation and potential evapotranspiration) are easily amenable to producer intervention, targeting residual soil nitrogen (RSN) is the only practical option for managing the risk of water contamination by nitrogen. The only exception might be to use irrigation to compensate for insufficient precipitation. When episodes of drought during the growing season hinder crop growth and N uptake, supplemental irrigation can be used to both increase yields and reduce the amount of RSN. Moreover, Drury et al. (1996) found that by manipulating the water table depth, nitrate losses could be decreased and the nitrate concentration in tile drainage water reduced. Management practices that can help to mitigate the risk of elevated RSN, and thus reduce the risk of water contamination by nitrogen, are described in Chapter (9) on RSN.

Another management option available to producers consists in growing cover crops (lower-value crops planted in the fall after the main higher-value crop has been harvested). The cover crop would take up excess soil nitrogen, thereby preventing leaching losses, and they would also extend the growing season, helping to reduce the over-winter precipitation surplus.

■ REFERENCES

Baier, W. and G.W. Robertson, 1965. *Estimation of Latent Evaporation From Simple Weather Observations*. Canadian Journal of Plant Science. 45: 276 – 284.

Chambers, P.A., M. Guy, E.S. Roberts, M.N. Charlton, R. Kent, C. Gagnon, G. Grove, and N. Foster (eds), 2001. *Nutrients and Their Impact on the Canadian Environment*. Environment Canada, Ottawa (Ont.).

Drury, C.F. and C.S. Tan, 1995. *Long-Term (35 Years) Effects of Fertilization, Rotation and Weather on Corn Yields*. Canadian Journal of Plant Science. 75: 355-362.

Drury, C.F., C.S. Tan, J.D. Gaynor, T.O. Oloya, and T.W. Welacky, 1996. *Influence of Controlled Drainage-Subirrigation on Surface and Tile Drainage Nitrate Loss*. Journal of Environmental Quality. 25: 317-324.

MacDonald, K.B., 2000. *"Risk of Water Contamination by Nitrogen"*. Pages 117-123 in Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project, T. McRae, C.A.S. Smith, and L.J. Gregorich (eds.). Agriculture and Agri-Food Canada, Ottawa (Ont.). www.agr.gc.ca/env/naharp-pnarsa

18. Phosphorus

SUMMARY

Phosphorus is added to agricultural soils in the form of inorganic fertilizers, manure and other organic products to optimize agronomic yields and, more broadly speaking, to meet the increasing demand for food and fibre. The Indicator of the Risk of Water Contamination by Phosphorus (IROWC-P) has been developed to assess the relative risk of phosphorus moving from treated agricultural areas into nearby water bodies, where it can contribute to algae growth and eutrophication. Risk of water contamination by phosphorus may be especially high in areas where agricultural soils are rich in phosphorus or have excess phosphorus relative to crop needs. The risk is higher in areas that have a high potential for soil erosion and surface run-off.

The IROWC-P could only be derived for Quebec because of limited data availability for the other provinces. Most of the farmland in Quebec falls into the low risk and moderate risk classes (30% and 50% respectively in 2001). In 2001, 15% of agricultural land was in the high risk class of water contamination by phosphorus, mostly concentrated in the regions of Montréal-Nord, Montérégie and Chaudière-Appalaches. This high risk situation is likely due to a combination of more phosphorus-saturated soils, higher potential for soil erosion and surface run-off and more intensive agricultural production. The indicator showed an important shift of farmland from the high and moderate risk classes, to the low risk class during the 20 year period (1981-2001).

AUTHORS:

E. van Bochove,
G. Thériault,
F. Dechmi and
M.-L. Leclerc

INDICATOR NAME:

Indicator of the Risk of Water Contamination by Phosphorus (IROWC-P)

STATUS:

Provincial coverage (Quebec), 1981 to 2001

THE ISSUE

Phosphorus (P) is an essential nutrient for plant growth. Crop fertilization with this nutrient has become a common agronomic practice since the late 1950s. Phosphorus is added to agricultural soils in the form of inorganic fertilizers, manure and other organic products to optimize agronomic yields and the economic viability of agricultural enterprises, as well as to meet the increasing demand for food and fibre.

However, the addition of phosphorus is not always without risks. Some phosphorus may eventually move from treated agricultural areas into the surrounding environment, notably into water resources. When phosphorus becomes concentrated in surface waters, it can cause very high levels of algal growth and decomposition, leading to eutrophication of the aquatic environment (Carpenter et al. 1998). A number of environmental measures have been implemented to reduce or eliminate point sources of anthropogenic phosphorus inputs to water (e.g. detergents, municipal wastewater), resulting in positive effects on water quality. In many areas, remaining phosphorus inputs to water are now largely agricultural in origin. Controlling non-point source phosphorus pollution from agricultural soils is therefore a major challenge in efforts to protect surface waters. The problem is more significant in areas where the risk of water erosion or run-off is combined with the presence of P-rich soils that have a reduced capacity to retain phosphorus owing to repeated fertilizer and manure applications (for example, areas with high livestock density) and in areas where the soil P content exceeds plant needs (Beauchemin and Simard 2000).

THE INDICATOR

The processes by which phosphorus is transferred from soils to water bodies are complex, and little is known about the amount that reaches surface waters naturally. It is therefore difficult to measure how much phosphorus from farmland actually reaches surface waters. The Indicator of the Risk of Water Contamination by Phosphorus (IROWC-P) has been developed as a qualitative assessment tool for rating specific geographic units—Soil Landscape of Canada (SLC) polygons with more than 5% of their area dedicated to agricultural activity—based on the relative risk (compared to other units) of phosphorus moving from the land into adjacent surface waters, given the soil P saturation level and the quantity of P inputs.

The IROWC-P indicator is expressed as the proportion of agricultural land that falls into five different risk classes (very low, low, moderate, high and very high). The risk classes were established mainly on the basis of soil P chemistry and surface run-off potential. The very low to moderate risk classes generally indicate that the environment can support agriculture without major changes to management practices. In contrast, the high and very high risk classes indicate that excess P is being generated, that the soils are excessively rich in P or that significant P transport mechanisms are at play. The performance objective for this indicator is to have an increasing amount of agricultural land in the low risk classes (Classes 1 and 2).

■ CALCULATION METHOD

The IROWC-P was calculated at the SLC polygon level for Quebec only, for the period from 1981 to 2001. The indicator builds on a phosphorus indexing system initially developed by American scientists (Lemunyon and Gilbert 1993) and subsequently adapted to Canadian conditions (Bolinder et al. 2000). It is essentially a summation of the individual risks associated with three components (soil P levels, annual P balance and P movement from soil to water) that is used to assess the overall risk that an agricultural soil with a given degree of P saturation will receive a given quantity of P and lose it to streams and rivers.

The soil phosphorous levels component (P content and degree of soil P saturation) was estimated using the description and origin of the parent materials for the dominant soil series of each agricultural SLC polygon. This estimation was done on the basis of two soil studies.

For the phosphorus balance component, manure P was estimated using livestock population numbers from the Census of Agriculture, and fertilizer P was estimated using economic data (fertilizer sales data). Excess P (P unused by crops) was then calculated by linking these two estimates to crop production using cropping area data from the Census of Agriculture (for pasture, field crops, vegetable crops and potato crops), fertilization grid data, harvest coefficients and revised yield estimates.

For the P movement component, soil erosion by water and surface run-off are considered as the pathways of P transport from agricultural fields to surface waters. The potential of P loss by water erosion is estimated using the Revised Universal Soil Loss Equation adapted for Canada, which considers rainfall pattern, topography, land use practices and crop type. The surface run-off potential is determined using a modified matrix initially developed by McFarland et al. (1998) that takes into account the dominant soil slope class (from the SLC descriptive database) and curve number (derived from land use, cropping practices, hydrological conditions and soil hydrological group) for each polygon. The hydrological conditions were considered good for all SLC polygons, and the soil hydrological group was estimated on the basis of the dominant soil series drainage class.

■ LIMITATIONS

The IROWC-P has been calculated only for Quebec because data on soil P content and degree of P saturation, which are essential for calculating phosphorus status and phosphorus balance components, are not currently available for the other provinces. Because only one soil survey was available, it was not possible to evaluate soil-P enrichment caused by changing agricultural management practices for the entire period covered. Additionally, a number of agricultural management practices that are likely to have a significant impact on the risk calculations have not been integrated into the indicator due to a lack of data. These practices include the addition of *phytase* to livestock feed, resulting in reduced manure P content, as well as various manure management or application methods. The available data on inorganic fertilizer use, based on sales, allowed only rough estimates at the polygon scale. The calculation of the risks of P transport from soil to water bodies takes into account the main mechanisms of P transport (soil erosion by water and surface run-off), but it does not consider additional hydrological processes or the connectivity of agricultural land to drainage networks. The estimate of surface run-off does not include the effect of snow melt or interannual and interseasonal climate fluctuations. Polygons for which a component could not be calculated because of data gaps were systematically removed from the calculation. This procedure inevitably underestimated the total area of farmland relevant to this indicator.

The results show a net increase in the proportion of farmland grouped in the low risk class.

The objective of expanding the IROWC-P to the national level for the year 2008 necessitates the creation of a national soil-P saturation database. The sources used to develop the databases have to allow updates for every Census of Agriculture year. Additionally, an improved transport component is currently being developed to include hydrological aspects lacking in the present IROWC-P. Finally, due to the numerous data sources used in indicator calculation, a methodology needs to be developed to quantify the uncertainty associated with the calculations. This uncertainty value is fundamental to provide a qualitative appreciation of a science-based indicator.

■ RESULTS

Table 18-1 shows the risk distribution for the 20-year period of the IROWC-P indicator, and Figure 18-1 shows the geographical distribution of the farmland in the five IROWC-P classes in Quebec for 2001.

The results show that, between Census years 1981 and 2001, the total area of farmland remained relatively constant. A net increase in the proportion of farmland grouped in the low risk class is observed between the 1981-1991 and 1996-2001 intervals (increases of roughly 15% and 30%, respectively), whereas the proportion of land grouped in the moderate risk class varied between roughly 65% and 50%. In each Census year, approximately 18% of farmland in Quebec fell into the high risk class; no farmland was in the very high risk class; and about 1% or less was in the very low risk class.

■ INTERPRETATION

The results have to be interpreted in light of the substantial changes that occurred in the agricultural landscape during the period under study. Although the total area of farmland remained relatively constant, the area planted with grain corn, a high phosphorus-demanding crop, expanded by as much as 144%. Between 1991 and 2001, the dairy cattle herd declined by 21%, whereas swine and poultry operations increased by 46% and 32%, respectively. Over the last ten years, these changes in the livestock industry resulted in a 9% increase in the total

Table 18-1: Share of Quebec farmland in IROWC-P classes, 1981 to 2001

Share of Quebec Farmland in Classes of Risk of Water Contamination by P (in %)

Year	1981	1986	1991	1996	2001
Very Low Risk	0	1	0	1	0
Low Risk	18	19	11	33	29
Moderate Risk	63	65	61	48	55
High Risk	18	15	27	18	16
Very High Risk	0	0	0	0	0

amount of phosphorus available from manures and a 27% decrease in P fertilizer sales. In such a context, producers are inclined to plant more extensive areas with high phosphorus-demanding crops so they can spread the P-enriched manure. This partially explains the decrease in P fertilizer sales. In some regions where farmland is limited, there has been an upward trend in forest clearing activities.

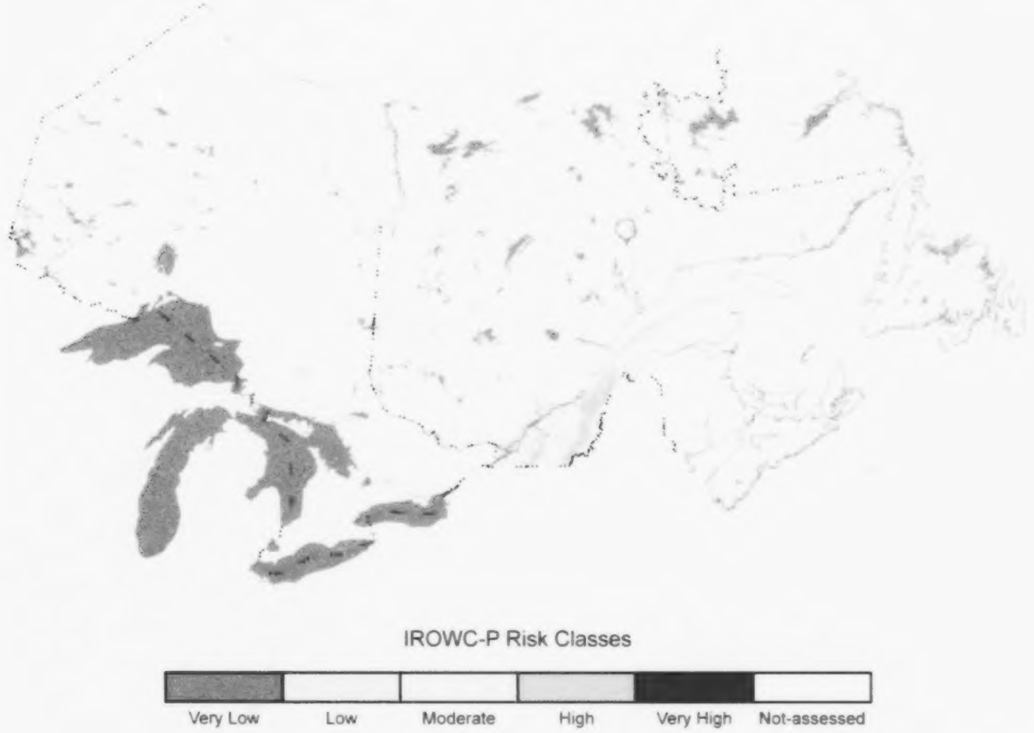
During the five Census years covered (1981 to 2001), 67% to 71% of the agricultural area had a moderate run-off potential, whereas 18% to 21% of the area under cultivation had a high and very high potential. Erosion presented the same risk proportions as run-off. Nonetheless, the temporal trends showed that the increase in wide-row crops (corn and soybeans) between 1981 and 2001 increased the risk of sediment transport only slightly.

The high risk class assigned to some regions of Quebec (e.g. Montréal-Nord, Montérégie and Chaudière-Appalaches) can be attributed to a combination of factors, such as a higher level of soil P saturation, a higher potential for soil erosion and surface run-off and more intensive agricultural production.

■ RESPONSE OPTIONS

Phosphorus losses from agricultural land and their transport to water resources can be reduced significantly through the adoption of various beneficial management practices. In fact, since the introduction of several codes of practice and government regulations (*Regulation Respecting the Reduction of Pollution from Agricultural Sources, 1998* and the *Agricultural Operations Regulation, 2002*), a number of beneficial management

Figure 18-1: Risk of Water Contamination by Phosphorus on farmland in Quebec under 2001 management practices



practices have been adopted to control water contamination by phosphorus in Quebec, especially in intensively farmed areas with excess phosphorus. Such practices are generally aimed at reducing the impact of agricultural production in areas that are susceptible to soil erosion by water and surface run-off, but also at balancing plant nutrient requirements with soil P content through the development of rigorous fertilization plans.

In general, where risk is relatively low, practices aimed at limiting phosphorus movement appear to be appropriate for reducing the risk of P transport from agricultural soils to surface waters (e.g. controlling soil erosion and surface run-off, preventing livestock access to streams, balancing phosphorus inputs based on crop requirements and soil P content). Areas with a higher risk level may be richer in phosphorus or more prone to P transport. A detailed assessment of the causes of the high risk status must be conducted to identify suitable corrective measures. These measures may include compliance with agri-environmental fertilization plans; using high phosphorus-demanding rotation crops; limiting manure-phosphorus production; and installing riparian buffers and windbreaks. In addition, it may be important to limit the clearing and cultivation of forested lands, organic soils and marginal lands, since they play a key role as a "phosphorus filter" at the watershed level, reducing the impact of agricultural production on water quality.

■ REFERENCES

Beauchemin, S. and R.R. Simard, 2000. *Phosphorus Status of Intensively Cropped Soils of the St. Lawrence Lowlands*. Soil Science Society of America Journal. 64: 659-670.

Bolinder, M.A., R.R. Simard, S. Beauchemin and K.B. MacDonald, 2000. *Indicator of Risk of Water Contamination by P for Soil Landscape of Canada Polygons*. Canadian Journal of Soil Science. 80: 153-163.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howath, A.N. Sharpley and V.H. Smith, 1998. *Nonpoint Pollution of Surface Waters With Phosphorus and Nitrogen*. Ecological Applications. 8 (3): 559-568.

Lemunyon, J. L. and R.G. Gilbert, 1993. *The Concept and Need for a Phosphorus Assessment Tool*. Journal of Productive Agriculture. 6: 483-486.

McFarland, M.A.A., L. Hauck, J. White, W. Donham, J. Lemunyon, and S. Jones, 1998. *"Nutrient Management Using a Phosphorus Risk Index for Manure Application Fields"*. Pages 241-244 in Proceedings of Manure Management in Harmony with the Environment and Society, Paper No. 62 of the Manure Management Conference Proceedings Feb.10-12, 1998. Soil and Water Conservation Society (SWCS), Ankeny (Iowa).

19. Pesticides

AUTHORS:
A. J. Cessna,
A. Farenhorst
and D.A.R.
McQueen

INDICATOR NAME:
Indicator of the Risk of Water Contamination by Pesticides (IROWC-Pest)

STATUS:
Currently under development

■ SUMMARY

Pesticides used in agriculture may move from the area where they are applied into the broader environment and eventually contaminate surface and ground waters, with potential environmental and human health implications. An Indicator of the Risk of Water Contamination by Pesticides (IROWC-Pest) is currently under development. The indicator will provide relative estimates of the risk of water contamination by pesticides in agricultural areas of Canada, as influenced by the type and quantity of pesticide used, soil landscape characteristics, the environmental conditions under which these substances are applied and the use of beneficial management practices.

■ THE ISSUE

Pesticides are an important part of Canadian crop production, with more than 45 million kilograms of pesticides being applied annually in Canada. These chemicals are used to control crop damage and prevent economic losses caused by crop pests. While their use has helped to increase crop yields and value, pesticides may also contribute to environmental degradation. For example, pesticides in run-off may contaminate surface waters, while leaching of these substances may lead to contamination of *ground water*. Small amounts of pesticide residues are often found in surface and ground waters in Canada (Donald et al. 2001, Frank et al. 1987, Frank et al. 1990, Grover et al. 1997, Lampman 1995, Rudolph and Goss 1993); however, the consequences to human health of exposure to low levels of pesticides over long periods of time or the effects on wildlife and wildlife habitat are not well understood. The potential environmental impacts of pesticide use therefore remain an important concern for Canadians.

Over the past 20 years, significant progress has been made in reducing the potential for the movement of pesticides from the farm field to surface and ground waters. Beneficial management practices can be adopted that mitigate the movement of pesticides off-site or reduce the amount of pesticides applied to fields. In addition, as a result of improved pesticide efficacy, present-day pesticides tend to be more selective and less toxic than their predecessors and applied at lower rates of application.

■ THE INDICATOR

The Indicator of the Risk of Water Contamination by Pesticides (IROWC-Pest), currently under development, will assess the relative risk of water contamination by pesticides used in agriculture. This risk will be calculated by estimating the movement of pesticides from farm fields to the surrounding environment. The indicator will consider the risk of ground water contamination from pesticide leaching through soil to a one metre depth, as well as the risk of surface water contamination from pesticide drift, surface run-off and transport on water and wind eroded soil.

IROWC-Pest will take into account environmental conditions, the use of agricultural beneficial management practices, pesticide use (type, quantity), application technology, atmospheric inputs of pesticides and physical-chemical properties (e.g. pesticide field half life), all of which can affect the movement of pesticides from the point of application. This indicator will be most responsive to the adoption of beneficial management practices in Soil Landscape of Canada (SLC) polygons where environmental factors are favourable for pesticide movement.

■ CALCULATION METHOD

The two main factors that go into calculating the risk of water contamination are how much pesticide is being applied and what proportion is moving into the surrounding environment. Estimates of pesticide movement into the surrounding environment will be made using selected pesticide fate models which take into account characteristics of the soil, climate and pesticide, as well as management practices.

Correlations between crops grown and pesticide usage will be used to establish transfer functions which will then be applied to Statistics Canada cropping data to determine which and the quantity of pesticides are being applied in individual SLC polygons.

Validation will be done using historical pesticide monitoring data, collected by various organizations, to determine if the risk predicted by the indicator is reflected in the pesticide concentrations observed in ground and surface waters.

■ LIMITATIONS

Pesticide movement is very complex and encompasses several transport pathways or means through which these chemicals enter the surrounding environment. Leaching (matrix flow) is the first transport pathway that will be incorporated into the indicator. The complexity of the indicator will increase with the addition of pesticide application drift and eventually surface runoff and the transport of pesticides on wind and water eroded soil. The lack of available pesticide use data represents a challenge to the development of this indicator, and unless this issue can be resolved for example, by farm surveys, the indicator calculations will consist of estimates of pesticide use based on transfer functions.

The Indicator will assess the relative risk of water contamination by pesticides used in agriculture.

■ RESULTS

This indicator is currently under development and results are not yet available.

■ RESPONSE OPTIONS

This indicator has not been developed sufficiently to permit assessment at present. However, when IROWC-Pest is fully developed, it should be responsive to adoption of management practices that affect the amount and type of pesticide used, as well as the environmental and agronomic conditions under which pesticides are applied. Management practices that reduce pesticide transport from the area of application to the broader environment include integrated pest management (IPM), low drift nozzles, and buffer strips.

■ REFERENCES

Donald, D.B., N.P. Gurprassad, L. Quinnett-Abbott, and K. Cash, 2001. *Diffuse geographic distribution of herbicides in northern prairie wetlands*. Environmental Toxicology and Chemistry. 20: 273-279.

Frank, R., B.S. Clegg, B.D. Ripley, and H.E. Braun, 1987. *Investigations of pesticide contamination in rural wells, 1979-1984, Ontario, Canada*. Archives of Environment Contamination and Toxicology. 16: 9-22.

Frank, R., H.E. Braun, B.D. Ripley, and B.S. Clegg, 1990. *Contamination of rural ponds with pesticide, 1971-85, Ontario, Canada*. Bulletin of Environment Contamination and Toxicology. 44: 401-409.

Grover, R., D.T. Waite, A.J. Cessna, W. Nicholaichuk, D.G. Irvine, L.A. Kerr, and K. Best, 1997. *Magnitude and persistence of herbicide residues in farm dugouts and ponds in the Canadian prairies*. Environmental Toxicology and Chemistry. 16: 638-643.

Lampman, M., 1995. *Susceptibility of groundwater to pesticide and nitrate contamination in predisposed areas of southwestern Ontario*. Water Quality Research Journal of Canada. 30: 443-468.

McNaughton, D.C., and A.S. Crowe, 1995. *Investigation of Pesticides in Groundwater at Three Irrigated Sites Near Outlook, Saskatchewan*. Water Quality Research Journal of Canada. 30 (3) : 399-427.

Rudolph, D. and M. Goss (eds.), 1993. *Ontario farm groundwater quality survey: summer*, 1992. Agriculture Canada, Federal-Provincial Land Management Assistance Program, Ottawa (Ont.). 162 p.

20. Pathogens

AUTHORS:
E. Topp,
E. van Bochove,
G. Thériault,
F. Dechmi and
D. Lapen

INDICATOR NAME:
Indicator of the Risk of Water Contamination by Pathogens (IROWC-Path)

STATUS:
Currently under development

SUMMARY

The use of bovine, swine and poultry manures to optimize crop growth may pose risks to human health and the environment, as various pathogenic organisms, including bacteria, viruses and parasites, may be found in these products. Under certain conditions, these pathogenic micro-organisms can migrate from farmland into groundwater or be carried into surface water by run-off. An indicator is being developed—the Indicator of the Risk of Water Contamination by Pathogens—for assessing the likelihood that pathogenic micro-organisms in manure will reach surface water. The indicator will initially focus on enteric bacteria.

THE ISSUE

Bovine, swine and poultry manures are extremely valuable sources of nutrients and are used by many producers to optimize crop growth. Since manure can harbour pathogenic organisms, including bacteria, viruses and parasites, the use of these materials as fertilizers may pose risks to human health and the environment. Under certain conditions, pathogenic micro-organisms from stored or applied manure can migrate from farmland into groundwater or be carried into surface water by run-off. The consequences of high levels of contamination of recreational or drinking water by these organisms can include human illness, increased capital costs for water treatment and economic loss through denial of use of recreational waters. This may also translate into more severe restrictions on the expansion or siting of livestock production facilities.

THE INDICATOR

The Indicator of the Risk of Water Contamination by Pathogens (IROWC-Path) is currently in the early stages of development. Once completed, it will permit assessment of the potential risk of water becoming exposed to fecal pollution of agricultural origin by considering the following key elements:

- Manure application: The manure application rate influences the level of risk (proportional to application rate). The risk is mitigated through various application practices (e.g. incorporation of manure into the soil).
- Manure storage: The duration of storage and the form in which manure is stored can influence pathogen content (longer storage is better than short; liquid is generally safer than solid).
- Manure treatment: Various manure treatments can attenuate pathogen content and reduce risk (e.g. *composting*).
- Persistence: The viability of pathogens in the environment is influenced by a variety of factors such as the soil temperature during manure application periods.
- Hydrological considerations: Major exposure pathways (*preferential flow*, drainage, run-off) affect the distribution of pathogens in surface water and groundwater. Land and soil characteristics, such as slope and *soil texture* and connectivity to water bodies, also have an effect.

CALCULATION METHOD

The Indicator of the Risk of Water Contamination by Pathogens will be calculated at both the Soil Landscape Canada (SLC) polygon level and the watershed level. The quantity and quality of manure used on agricultural land will be linked with a hydrologic component to assess the likelihood that pathogenic micro-organisms in the manure will reach surface water or groundwater.

Data on the quantity of manure used at the SLC polygon level are already available from the Census of Agriculture database. This variable consists of a summation of the annual calculated manure production from major livestock categories (beef, dairy, pigs, poultry, etc.). Attenuation and amplification weighting coefficients specific to the origin of the manure, to the different management practices (storage and treatment), to the climatic conditions at the time of application and to any other conditions that have a direct effect on micro-organism persistence will be used in the indicator algorithm. Although these coefficients may be subjective, they will be science-based and agreed upon by subject-matter experts at the provincial and national levels prior to their use in indicator calculation.

Pathogen transport will be estimated on the basis of surface run-off and subsurface flow as well as other factors accounting for hydrological connectivity between sources and water bodies. A soil-water balance approach will be used to quantify excess soil water that runs off cropland as surface and/or subsurface flow using the modified Versatile Soil Moisture Budget model (Akinremi et al. 1996). The soil-water balance will be calculated daily, to take pathogen survival time into account. The hydrological connectivity between pathogen sources and water bodies will then be modelled using data on the following aspects: (i) the propensity of an area to water excess run-off (topographic index); (ii) the potential for pathogens to be exported from soils that are intensively drained (tile drainage, preferential flow); and (iii) surface drainage density (ditches, brooks, rivers, ponds, lakes, etc.).

> *The Indicator will permit assessment of the potential risk of water becoming exposed to fecal pollution of agricultural origin.*

LIMITATIONS

There are still a lot of unknowns regarding the pathogen content of various manures and the specific impact that various treatments and exposure pathways have on the persistence of these pathogenic micro-organisms in the environment following manure application. Also, the pathogens considered by this indicator will, at least initially, only include pathogenic bacteria. It is still not known whether the kinetics of persistence and the exposure pathways used in the calculations will be applicable to other micro-organisms of concern (e.g. enteric viruses or parasites such as *Cryptosporidium*).

RESULTS

This indicator is currently under development and results are not yet available.

RESPONSE OPTIONS

This indicator is not yet sufficiently developed to make specific suggestions on the approaches that producers in different regions of Canada could adopt in order to minimize the risk of contamination of water by pathogenic micro-organisms. However, when IROWC-Path is fully developed, it will be responsive to the key changes in management practices that affect the amount and characteristics of manure used on agricultural land, as well as the environmental and agronomic conditions under which they are applied. Beneficial management practices that can reduce pathogen movement are likely to include a variety of manure management options for treatment (e.g. composting), application (e.g. rate) and land use (e.g. offset distances), as well as erosion and surface run-off control measures, such as *riparian buffer strips*.

REFERENCES

Akinremi, O.O., S.M. McGinn, and A.G. Barr, 1996. *Simulation of Soil Moisture and Other Components of the Hydrological Cycle Using a Water Budget Approach*. Canadian Journal of Soil Science. 76 (2):133-142.

Kirkby, M.J., 1975. *"Hydrograph Modelling Strategies"*. Pages 69-90 in Processes in Physical and Human Geography, R. Peel, M. Chisholm, and P. Haggett (eds). Heinemann, London (England).

U.S. Department of Agriculture, 1972. *"Hydrology"*. Chapter 10.5-10.6 in National Engineering Handbook. USDA, Soil Conservation Service, Washington.

Air Quality

E

21. Greenhouse Gases

AUTHORS:
R.L Desjardins,
X. Vergé,
J. Hutchinson,
W. Smith,
B. Grant,
B. McConkey and
D. Worth.

INDICATOR NAME:
Agricultural Greenhouse Gas Budget

STATUS:
National coverage, 1981 to 2001

■ SUMMARY

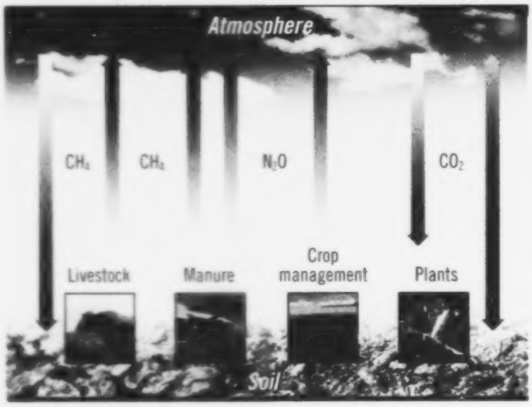
Under the Kyoto Protocol, Canada has made an international commitment to reduce its greenhouse gas (GHG) emissions to 6% below the 1990 levels by 2012. The agriculture sector has the potential to help Canada achieve this objective. GHG emissions from agricultural sources include three gases: nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2). In 2001, net emissions of these three gases from on-farm practices (excluding emissions associated with the use of fossil fuel) were estimated at 53.1 Mt CO_{2eq}[1], or about 8% of Canada's total GHG emissions. Between 1981 and 2001, on-farm GHG emissions decreased by 6.0 % (3.4 Mt CO_{2eq}), largely as a result of agricultural soils changing from being a source of 8.2 Mt CO_2 to a sink of -4.4 Mt CO_2. During the same period, nitrous oxide emissions increased from 24.7 to 31.7 Mt CO_{2eq} and methane emissions increased from 23.6 to 25.8 Mt CO_{2eq}. Improved management practices can reduce GHG emissions from agricultural sources and to mitigate the rise in atmospheric CO_2 levels by sequestering (storing) carbon in agricultural soils. Improved management practices may also help to reduce inefficiencies in fertilizer use and land management, generating economic gains for agricultural producers.

■ THE ISSUE

In just one decade, the increase in greenhouse gas (GHG) concentrations in the atmosphere has become a matter of global concern. Recent reports by the Intergovernmental Panel on Climate Change (IPCC 2001) state that the higher levels of GHGs in the atmosphere are likely changing the earth's climate. The Kyoto Protocol was proposed as a tool for slowing down the increase in the atmospheric concentrations of GHGs. Reducing GHG emissions is particularly important for a country like Canada, which has a per capita rate of emission that is among the highest in the world. Through the Kyoto Protocol process, Canada has therefore made an international commitment to reduce its GHG emissions to 6% below the 1990 levels by 2012. With the Protocol having recently come into force, the pressure to implement policies that reduce GHG emissions is intensifying, as is the requirement to report net GHG emissions at the provincial and national levels using a consistent and transparent methodology.

There are many reasons for reducing GHG emissions in agriculture. Direct emissions of greenhouse gases from agriculture not only contribute significantly to overall GHG emissions in Canada (estimated to be 8% of Canada's overall emissions in 2001, excluding fossil fuel use), they reflect a loss of nutrients and therefore a potential loss of income. Furthermore, agriculture is one of the sectors most likely to be affected by climate change (e.g. changes in production patterns, increases in crop damage, water shortages, new and unpredictable changes in the interactions between crops, weeds and insects). Through improved management practices, the agriculture sector has the potential to reduce its GHG emissions and to mitigate the rise in atmospheric CO_2 levels by sequestering carbon in agricultural soils (see Chapter 14). In so doing, it will support Canada's reduction commitment.

Figure 21-1: Main sources and sinks of GHG associated with agroecosystems



---

[1] Mt CO_{2eq} = 1 million tonnes "carbon dioxide equivalents"

■ THE INDICATOR

Figure 21-1 shows the main sources and sinks of greenhouse gases associated with agroecosystems. The Agricultural Greenhouse Gas Budget Indicator was developed to provide an estimate of the on-farm net emissions (emissions minus absorption) of three gases: nitrous oxide, methane and carbon dioxide.

There are three sources of nitrous oxide emissions: (1) direct emissions from agricultural fields (arising from mineral fertilizers, manure used as fertilizer, crop residues and the cultivation of organic soils); (2) direct emissions from animal production systems (collection and storage of manure and direct deposition of manure on pasture by grazing animals); and (3) indirect emissions (volatilization and atmospheric deposition of ammonia, nitrogen leaching and run-off). Methane emissions come mainly from farm animals, from the anaerobic decomposition of manure and from soils which may act as a source or sink for methane, depending on moisture conditions. In this report, direct carbon dioxide emission (or absorption) by soils is captured by the Soil Organic Matter on Cropland Indicator (see Chapter 14 for details). It should be noted that carbon dioxide is also emitted during fossil fuel combustion by farm machinery and from the manufacturing of fertilizers and machinery used in agriculture. However, these indirect sources of GHGs are typically captured under transportation and manufacturing sector reporting and are therefore not included in the estimates presented in this report. The performance objective for this indicator is to have declining net emissions of greenhouse gases over time (a specific reduction target has not yet been established for agriculture).

■ CALCULATION METHOD

The methodology of the Intergovernmental Panel on Climate Change (IPCC) was used to calculate nitrous oxide and methane emissions, whereas the Century Model was used to estimate net carbon dioxide exchange. The IPCC methodology involves three basic steps:

1) collecting information on animal populations, amount of manure produced, manure storage and treatment system used, amount of fertilizer applied, type of crop planted, etc.

2) selecting the *emission factors* associated with various management practices, either taken from the literature or based on experimental data.

3) calculating the GHG emissions by multiplying the emission factors by either the amount, the population or the area involved.

Methane is emitted through enteric fermentation and manure management. For enteric fermentation these three steps are performed at two levels of detail (Vergé et al. 2005). The first level of detail relies on the use of default emission factors from the IPCC. It is used to calculate methane emissions for animal categories considered to be of lesser importance as a methane source (sheep, goats, horses, bison and swine). The second level of detail uses country-specific information to calculate emissions for animals considered to be the main sources of methane (dairy and non-dairy cattle). For manure management, the second level of detail was used for all livestock categories.

In the case of nitrous oxide, a recently revised IPCC methodology, adjusted for conditions in Canada, was used to calculate emissions (Hutchinson et al. 2005). Finally, carbon dioxide emissions from soils were estimated using the Century Model (see Chapter 14).

The *Global Warming Potential (GWP)* of each gas was used to allow comparison and combined reporting. GWP is the contribution that a gas makes to the greenhouse effect according to its capacity to absorb radiation and its residence time in the atmosphere. Although slightly different GWPs were recently estimated for methane and nitrous oxide (IPCC 2001), for this report we will use the GWPs commonly used for Kyoto Protocol reporting, namely 1 for carbon dioxide, 21 for methane and 310 for nitrous oxide (IPCC 1996). This means that one molecule of nitrous oxide or methane is 310 and 21 times more powerful greenhouse gas than carbon dioxide, respectively. Results are presented in table and map form, and are expressed in Mt CO_{2eq} or kg CO_{2eq}. Map scales were selected to best represent the variation in emissions across the country.

■ LIMITATIONS

The GHG calculation methodology developed by the Intergovernmental Panel on Climate Change (IPCC 1996) is an oversimplification for worldwide application. It does not consider local soil and climatic conditions and does not provide the accuracy that will soon be required of Kyoto Protocol signatories.

Revised emission factors that better reflect how management practices on Canadian farms affect the exchange processes that lead to nitrous oxide and methane emissions, as well as the absorption and emission of carbon dioxide from agricultural soils, were used when possible. However, much uncertainty remains because of the complexity of the interactions between soils, crops and climate. As more data specific to Canadian conditions become available, more accurate emission factors will be employed.

Between 1981 and 2001, net national GHG emissions from agriculture decreased from 56.5 Mt CO_{2eq} to 53.1 Mt CO_{2eq}.

■ RESULTS

Table 21-1 presents the evolution of net greenhouse gas emissions for Canadian agriculture over the last five Census years. The emissions of the three main greenhouse gases associated with agriculture are presented, as well as the total net GHG emissions. Also shown is the percentage change in net emissions between 1991 (the Census year closest to the Kyoto Protocol benchmark year) and 2001. Figure 21-2 presents the geographical distribution of net GHG emissions in Canada in 2001. As noted above, the results presented here do not include indirect sources of carbon dioxide emissions; however, these estimates are available on-line (Desjardins et al. 2005).

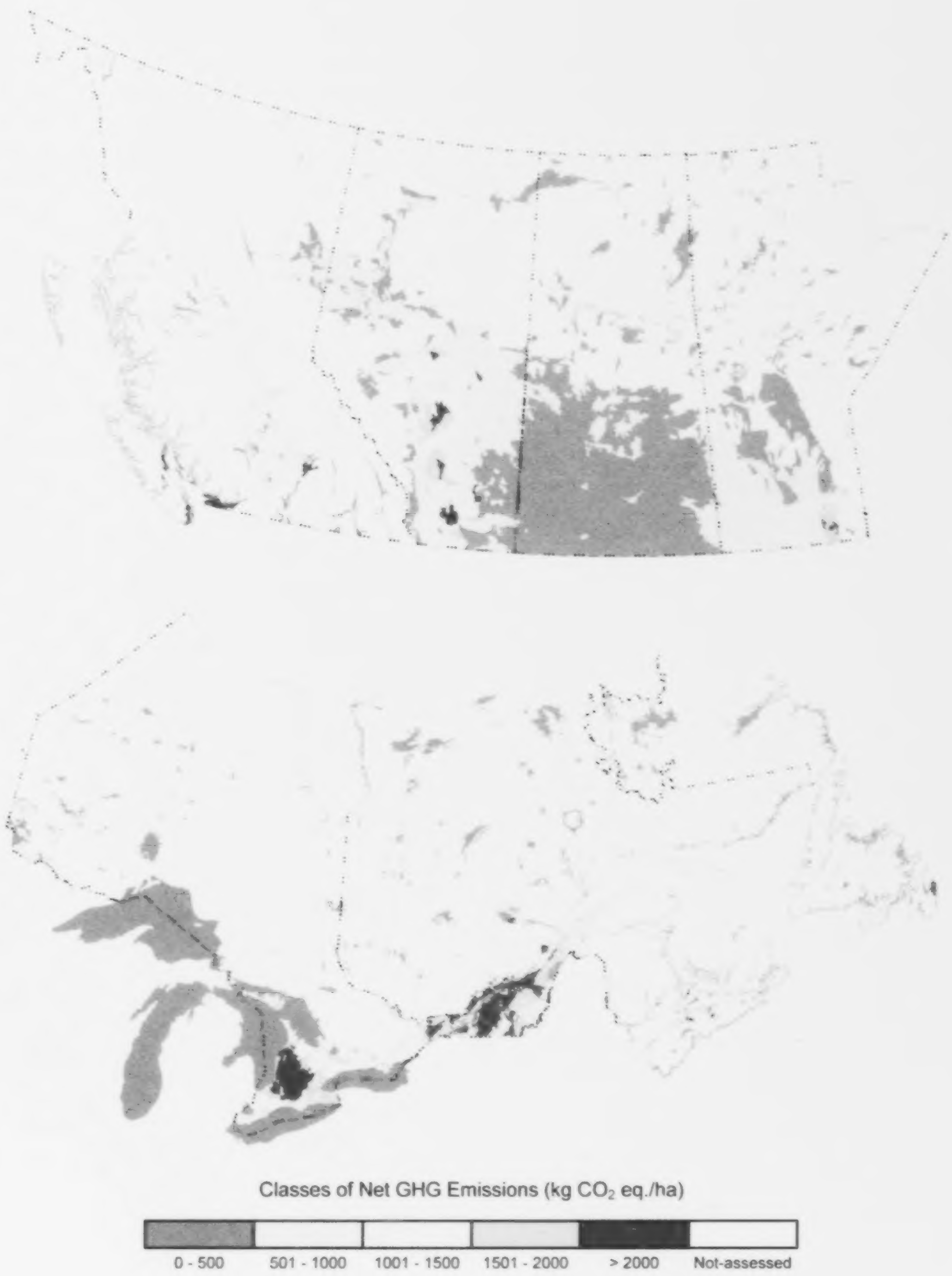
Canada: Between 1981 and 2001, net national GHG emissions from agriculture decreased from 56.5 Mt CO_{2eq} to 53.1 Mt CO_{2eq}. This decrease occurred despite increases in national agricultural nitrous oxide emissions (7.0 Mt CO_{2eq}) and methane emissions

Table 21-1: Net agricultural greenhouse gas emissions (excluding fossil fuel use) in Mt CO_{2eq} 1981 to 2001

Greenhouse Gas Emissions (Mt CO_{2eq})

Province	Methane (CH_4)					Nitrous Oxide (N_2O)					Carbon Dioxide (CO_2)					Net Emissions					% Change
	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01	81	86	91	96	01	91 to 01
BC	1.7	1.2	1.3	1.5	1.4	1.1	0.9	0.9	1.0	1.0	0.1	0.1	0.0	0.0	0.0	2.9	2.3	2.2	2.5	2.4	10%
AB	6.3	5.8	7.0	8.5	9.8	6.6	6.6	7.3	8.9	9.5	3.4	3.2	2.7	1.6	0.3	16.4	15.7	17.0	19.1	19.5	15%
SK	3.4	3.0	3.2	4.2	4.1	4.6	6.0	5.6	8.5	8.0	2.7	2.6	1.1	-2.4	-4.6	10.7	11.6	9.9	10.3	7.6	-24%
MB	2.0	1.9	1.9	2.4	2.6	2.9	3.5	3.7	4.5	4.7	1.4	1.3	0.7	0.1	-0.3	6.2	6.7	6.3	7.0	7.0	11%
ON	5.2	4.6	4.3	4.3	4.0	6.1	5.6	5.0	5.0	4.9	0.4	0.4	0.4	0.2	0.1	11.7	10.5	9.7	9.5	9.0	-7%
QC	4.1	3.7	3.4	3.5	3.3	3.0	2.9	2.8	3.0	2.9	0.0	-0.1	0.0	0.1	0.1	7.1	6.5	6.2	6.5	6.3	1%
Atlantic Prov.	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.6	0.7	0.2	0.2	0.1	0.1	0.0	1.5	1.5	1.2	1.3	1.3	4%
Canada	**23.6**	**20.9**	**21.8**	**25.0**	**25.8**	**24.7**	**26.1**	**25.8**	**31.4**	**31.7**	**8.2**	**7.7**	**5.0**	**-0.3**	**-4.4**	**56.5**	**54.7**	**52.5**	**56.1**	**53.1**	**1%**

Figure 21-2: Agriculture Greenhouse Gas Budget under 2001 management practices


Classes of Net GHG Emissions (kg CO2 eq./ha)
0 - 500
501 - 1000
1001 - 1500
1501 - 2000
> 2000
Not-assessed

(2.2 Mt CO_{2eq}). This decrease is due to a substantial increase in carbon sequestration in agricultural soils, which went from being a source of 8.2 Mt CO_{2eq} in 1981 to a sink of -4.4 Mt CO_{2eq} by 2001. The distribution and intensity of GHG emissions across the country (Figure 21-2) are directly related to the area and intensity of agricultural production.

British Columbia: There was a small decrease (-0.5 MT CO_{2eq}) in net GHG emissions in BC between 1981 and 2001, largely as a result of a reduction in CH_4 emissions (-0.3 MT CO_{2eq}). There was a little change in N_2O and CO_2 emissions over that time period.

Alberta: Of all the provinces, Alberta had the sharpest increase in GHG emissions between 1981 and 2001, from 16.4 to 19.5 Mt CO_{2eq} due to increases in methane (3.5 Mt CO_{2eq}) and in nitrous oxide (2.9 Mt CO_{2eq}). These increases were partly compensated by a reduction in CO_2 emissions (-3.1 Mt CO_{2eq}).

Saskatchewan: Emissions from Saskatchewan decreased by 3.1 Mt CO_{2eq} between 1981 and 2001, a trend largely explained by the fact that agricultural soils went from being a source of CO_2 in 1981 (2.7 Mt CO_{2eq}) to being a sink (-4.6 Mt CO_{2eq}) in 2001. This was sufficient to offset increases in methane and nitrous oxide emissions during that period (0.7 Mt CO_{2eq} and 3.4 Mt CO_{2eq} respectively).

Manitoba: GHG emissions from Manitoba increased by 0.8 Mt CO_{2eq} between 1981 and 2001. As in Saskatchewan, soils went from being a source of CO_2 (1.4 Mt CO_{2eq}) to being a sink (-0.3 Mt CO_{2eq}). However, this reduction was not as significant as the combined increase in methane (0.6 Mt CO_{2eq}) and nitrous oxide (1.8 Mt CO_{2eq}).

Ontario: Emissions from Ontario decreased by 2.7 Mt CO_{2eq} between 1981 and 2001, with this downtrend encompassing in all three GHGs: methane (-1.2 Mt CO_{2eq}), nitrous oxide (-1.2 Mt CO_{2eq}) and CO_2 (-0.3 Mt CO_{2eq}).

Quebec: Emissions from Quebec decreased slightly (-0.8 Mt CO_{2eq}) between 1981 and 2001. This downturn was supported by a decrease in methane (-0.8 Mt CO_{2eq}) and in nitrous oxide (-0.1 Mt CO_{2eq}), while CO_2 emissions increased slightly (0.1 Mt CO_{2eq}).

Atlantic: Combined GHG emissions from the four Atlantic Provinces showed a decrease of -0.2 Mt CO_{2eq} during the 20-year period, as a result of decreases in CO_2 and methane emissions. Note that results for the provinces of Newfoundland and Labrador, Prince Edward Island, Nova Scotia and New Brunswick have been combined, as emissions from these provinces are small.

■ INTERPRETATION

Net on-farm national GHG emissions, which had increased substantially in 1996, are close to those calculated in 1991, the closest comparison year to the Kyoto Protocol baseline of 1990. This decrease is mainly the result of changes in land use and management practices that led to a reduction in the area under summerfallow and an increase in the area under reduced tillage and no-tillage. These practices have significantly increased carbon sequestration in the agricultural soils of the Prairie Provinces by slowing the decomposition of crop residues. An increase in carbon sequestration has occurred in the agricultural soils of British Columbia and of Eastern Canada, but its magnitude is much smaller than the sequestration in prairie soils. Therefore, nationally, carbon sequestration in agricultural soils between 1981 and 2001 more than offset substantial increases in nitrous oxide and methane emissions.

Nationally, nitrous oxide emissions increased by 28% between 1981 and 2001. The largest increases in nitrous oxide emissions occurred in the Prairie Provinces primarily as a result of a large increase in the use of nitrogen fertilizer. This is especially true in Saskatchewan, where fertilizer sales increased by more than 200% between 1981 and 2001, as the traditional practice of underfertilization was reduced in order to better balance the removal/replacement ratio of nitrogen in prairie soils. In the Atlantic Provinces and in British Columbia, emissions were virtually unchanged between 1981 and 2001, while emissions decreased in Quebec and Ontario. This downturn reflects a 17% decrease in nitrogen fertilizer sales in Ontario and a reduction in emissions from animal waste and manure storage in both Ontario and Quebec as a result of a decrease in the total dairy and beef cattle population, which is discussed in more detail in the following paragraph.

Methane emissions are mainly due to enteric fermentation which represents 85% of the total methane emitted by livestock. The national increase observed between 1981 and 2001 is largely the result of an increase in enteric fermentation by growing beef cattle populations. The change in methane emissions was not uniform across the country, since emissions decreased or remained constant in Eastern Canada, but increased in Western Canada. This difference is mainly due to the type of cattle being produced and the change in the animal population in the east compared to the west. Eastern provinces posted a significant decrease in total dairy cow population from 1.4M head in 1981 to 0.8M head in 2001. At the same time, the total beef cattle population in the east has declined since 1981, with the exception of Quebec, where the population increased slightly (0.1M head). Since the methane emission factor for dairy cows is almost twice that for beef cattle, the decrease in the dairy cow population resulted in a net decrease in methane emissions in Eastern Canada. On the other hand, in the western provinces, the dairy cattle population was halved from 0.4M head in 1981 to 0.2M head in 2001, but the resulting decrease in methane emissions was small compared to the increase in methane emissions due to significant growth in the beef cattle population, which went from 7.4M head in 1981 to 10.5M head in 2001.

■ RESPONSE OPTIONS

There are many options available to Canadian farmers to reduce GHG emissions and increase soil sequestration of CO_2, through improved management practices (Janzen et al. 1999) such as improving the timing and rate of fertilizer application to suit crop and soil needs. In addition to sequestering CO_2, many of these management practices that can reduce GHG emissions may benefit producers by reducing inefficiencies in fertilizer use and land management.

Reductions in net GHG emissions from agricultural soils and increased carbon sequestration can be promoted by following recommended soil conservation practices, such as including more forage crops in rotations, using reduced tillage, decreasing land under summerfallow and converting marginal agricultural land to permanent grasslands.

Methane is produced mainly through enteric fermentation. The production of methane can be reduced by changing animal feed to reduce digestion time. This can be accomplished by using more easily digested feeds such as grains, legumes and silage; by harvesting forages at an earlier, more succulent growth stage; by feeding concentrated supplements as required; and by adding edible oils to the diet. Methane is also produced during the storage and decomposition of manure. If manure is stored as a liquid, or in poorly aerated piles, a lack of oxygen prevents the total decomposition of organic matter to carbon dioxide, resulting in the production of methane. Methane emissions from manure can be reduced by increasing aeration, by reducing manure storage time and by reducing the amount of bedding in manure.

Nitrous oxide emissions are usually associated with a buildup of nitrate (NO_3^-) in soils. Practices that have the potential to minimize this buildup include matching fertilizer application to crop needs, using slow release fertilizers, avoiding excessive manure applications, optimizing the timing of fertilizer application, using more appropriate fertilizer placement and using cover crops.

■ REFERENCES

Desjardins, R.L., X. Vergé, J. Hutchinson, W. Smith, B. Grant, B. McConkey, D. Worth, 2005. *The Greenhouse Gas Indicator for Canadian Agriculture*. Agriculture and Agri-Food Canada, Ottawa (Ont.).

Hutchinson, J.J., Desjardins R.L., D. Worth, Vergé X., 2005. *Agri-Environmental Indicator, Greenhouse Gas Emissions: Nitrous Oxide Component*. Agriculture and Agri-Food Canada, Ottawa (Ont.).

Intergovernmental Panel on Climate Change (IPCC), 1997. *"Chapter 4, Agriculture"* in Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories – Reference Manual, Vol. 3. IPCC, Bracknell (UK). http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.htm

Intergovernmental Panel on Climate Change (IPCC), 2001. *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds). Cambridge University Press, Cambridge (UK), 881pp. http://www.grida.no/climate/ipcc_tar/wg1/index.htm

Janzen, H.H., R.L. Desjardins, J.M.R. Asselin, and B. Grace, 1998. *The Health of our Air: Toward Sustainable Agriculture in Canada*. Agriculture and Agri-Food Canada, Ottawa (Ont.). http://res2.agr.ca/publications/ha/index_e.htm

Vergé, X., Desjardins R.L., D. Worth, J. Hutchinson, 2005. *Agri-Environmental Indicator, Greenhouse Gas Emissions: Methane Component*. Agriculture and Agri-Food Canada, Ottawa (Ont.).

22. Ammonia

AUTHORS:

S.C. Sheppard, S. Bittman and J. Tait

INDICATOR NAME:

Ammonia Emissions from Agriculture

STATUS:

Currently under development

■ SUMMARY

Ammonia (NH_3) emissions are an environmental and health concern in many nations, particularly owing to the potential for direct toxicity to natural vegetation, eutrophication of surface waters and production of fine particulate matter. An Indicator of Ammonia Emissions from Agriculture is being developed to assess the agricultural sector's contribution to this problem. The indicator will be based on total ammoniacal nitrogen and will cover aspects of feed nitrogen management and manure management as well as fertilizer sources. Several approaches may be available to decrease the total ammoniacal nitrogen in manure or to reduce ammonia losses from animal housing, manure storage and land application.

■ THE ISSUE

In Canada, anthropogenic ammonia emissions to the atmosphere are dominated by agricultural sources, mainly livestock production. Only a small proportion (roughly one-fifth) of the nitrogen consumed by farm animals in feed is retained by the animal; the rest is excreted in feces, urine and uric acid (poultry). Some of this nitrogen (especially in urine) will be converted to ammonia and emitted soon after excretion or during manure storage and application. Fertilizer, especially ammoniacal and urea fertilizer, is another potential source of ammonia.

Ammonia (NH_3) is a colourless gas, lighter than air, with a sharp odour. In the atmosphere, excess concentrations of ammonia have been linked locally (0.1–10 km from the emission source) to direct toxicity to vegetation and eutrophication of nitrogen-sensitive environments (Sheppard 2002). On a larger, regional scale (10–100 km from the source), ammonia contributes to acid rain and is a precursor to aerosol formation. These aerosols, primarily ammonium sulphate and ammonium nitrate, form in the atmosphere and contribute to the formation of fine particulate matter ($PM_{2.5}$), which is linked to the formation of *smog* and to potential health effects (see Chapter 23). There are two major areas of NH_3-mediated smog in Canada: the Fraser Valley and the Windsor–Montreal corridor.

Concern about the role of ammonia as a precursor to environmental and health impacts led Environment Canada to declare ammonia as a toxic substance under the Canadian Environmental Protection Act (CEPA) in June of 2003. Many countries, especially in Europe and North America, have recognized these issues. This is evidenced by the inclusion of ammonia in the international Gothenburg Protocol, which requires that all signatory nations quantify and reduce their emissions in relation to 1990 levels.

■ THE INDICATOR

While several options exist for the basic formulation of the Indicator of Ammonia Emissions from Agriculture, the approaches used in other parts of the world, notably Europe, may not be adequate for the Canadian situation. The major seasonal variations in climate and activities in Canada, as well as the focus on ammonia emissions as a precursor to smog episodes (not just toxicity to vegetation or eutrophication) has profound implications for both the indicator model formulation and the selection of parameter values.

The envisioned Indicator of Ammonia Emissions from Agriculture will therefore:

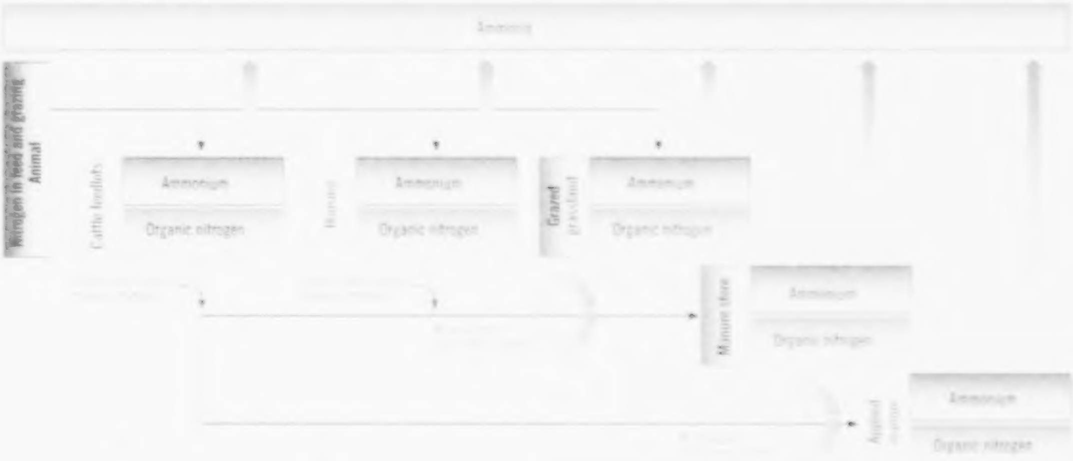
- be a total emissions indicator (deposition and net emission to be considered later);

- be based on emission estimates for portions of a year to reflect the seasonality of particulate matter formation, which is something not done in other national level indicators;
- be computed for geographical polygons that reflect sources of co-precursors to smog, such as non-agricultural (urban/industrial) emissions of sulphur oxides (SO_x) and, to a lesser extent, nitrous oxides (NO_x);
- be based on total ammoniacal nitrogen (TAN), with TAN tracked from excretion to land application;
- include aspects of feed nitrogen management;
- include fertilizer sources; and
- include functional relationships with climatic variables such as temperature.

CALCULATION METHOD

The basic model structure for the Indicator of Ammonia Emissions from Agriculture is illustrated in Figure 22-1. The model starts with the number of animals in a given livestock sector. An estimate is derived for the total ammoniacal nitrogen (TAN) that is excreted. The animals are assumed to be housed or fed or grazed, and a limited number of housing types is considered. Manure handling, storage and land application practices vary among livestock systems. The term 'manure management train' has been used to describe the series of steps involved in a given manure management approach. Once the amount of TAN has been partitioned among the management trains, the ammonia emissions are estimated for each activity using published emission factor (EF) values (adjusted to reflect the Canadian situation—e.g. variations in temperature).

Figure 22-1: Conceptual model of total ammoniacal nitrogen (TAN) flow in animal production systems


Ammonia
Nitrogen in feed and grazing
Animal
Cattle feedlots
Ammonium
Organic nitrogen
Housing
Ammonium
Organic nitrogen
Grazed
grassland
Ammonium
Organic nitrogen
Manure store
Ammonium
Organic nitrogen
Applied
manure
Ammonium
Organic nitrogen

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]

■ CALCULATION METHOD

[illegible]

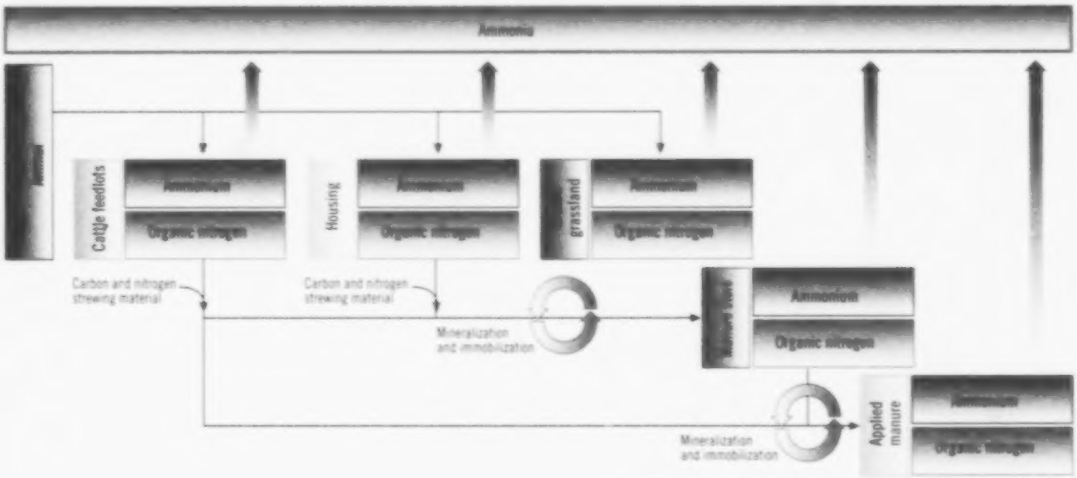
Figure 22-1: *Conceptual model of total ammoniacal nitrogen (TAN) flow in animal production systems*

- be based on emission estimates for portions of a year to reflect the seasonality of particulate matter formation, which is something not done in other national level indicators;
- be computed for geographical polygons that reflect sources of co-precursors to smog, such as non-agricultural (urban/industrial) emissions of sulphur oxides (SO_x) and, to a lesser extent, nitrous oxides (NO_x);
- be based on total ammoniacal nitrogen (TAN), with TAN tracked from excretion to land application;
- include aspects of feed nitrogen management;
- include fertilizer sources; and
- include functional relationships with climatic variables such as temperature.

■ CALCULATION METHOD

The basic model structure for the Indicator of Ammonia Emissions from Agriculture is illustrated in Figure 22-1. The model starts with the number of animals in a given livestock sector. An estimate is derived for the total ammoniacal nitrogen (TAN) that is excreted. The animals are assumed to be housed or fed or grazed, and a limited number of housing types is considered. Manure handling, storage and land application practices vary among livestock systems. The term 'manure management train' has been used to describe the series of steps involved in a given manure management approach. Once the amount of TAN has been partitioned among the management trains, the ammonia emissions are estimated for each activity using published emission factor (EF) values (adjusted to reflect the Canadian situation—e.g. variations in temperature).

Figure 22-1: Conceptual model of total ammoniacal nitrogen (TAN) flow in animal production systems


Ammonia
Cattle feedlots
Ammonium
Organic nitrogen
Housing
Ammonium
Organic nitrogen
grassland
Ammonium
Organic nitrogen
Carbon and nitrogen strewing material
Carbon and nitrogen strewing material
Mineralization and immobilization
Ammonium
Organic nitrogen
Mineralization and immobilization
Applied manure
Ammonium
Organic nitrogen

This computational process is replicated across the animal sectors (poultry, pig, beef and dairy), with separate accounting within these sectors for different animal classes (e.g. boars, sows and fatteners in the swine sector). Total ammonia emissions are summed across all animal sectors and classes, and all steps in the management trains. To this is added an estimate of NH_3 emissions from grazing and from fertilizers. These computations will be done for specific time periods within the year. Results will be reported as annual emissions (e.g. as Gg NH_3 yr^{-1}) of NH_3 to support international reporting efforts and comparisons. This annual value will have less direct meaning to stakeholders, however, because it encompasses all regions and sectors. Therefore, to provide a picture of regional and seasonal impacts, additional formulations will be computed that can be related to various mapping units, such as the Fraser Valley and the Windsor-Montreal corridor.

In Canada, anthropogenic ammonia emissions to the atmosphere are dominated by agricultural sources, mainly livestock production.

Crucial to the indicator is the availability of recent and accurate data on farm activities and practices. For example, information is needed on nitrogen in animal diets, on housing ventilation and on manure removal, storage and land-spreading practices. Surveys on farming activities, as well as expert opinions, will be required to provide credible activity data for the ammonia indicator.

■ LIMITATIONS

The availability of comprehensive activity data constitutes a major limitation. The model is very data intensive, requiring hundreds of parameters. The animal census data are the least problematic. The management activity data that will be used to define and categorize the manure management trains will be obtained largely from farmer surveys and interviews. Data gaps and inaccuracies may result from the survey process as well as from categorization, which can mask important details.

Also uncertain are the emission factor (EF) values. Few have been measured in Canada, and there are large uncertainties related to methodology and applicability for those measured overseas. Extrapolation methods may be required to adapt the EF data obtained from Europe to Canadian conditions, especially to account for climate and seasonality effects. There are also some important activities in Canada that have not been studied sufficiently in Europe. These include extensive grazing, sometimes on frozen soils, with centralized water sources, and cattle feedlots with compacted or frozen ground conditions.

■ RESULTS

This indicator is currently under development and results are not yet available.

■ RESPONSE OPTIONS

Ammonia emissions are linked to most major components of the livestock industry and usage of urea or ammonia containing fertilizers. As the number of potential mitigation measures in livestock systems is large, it would seem most beneficial to focus on components that also encompass other aspects of nutrient management. For example, phase feeding and related techniques for matching the nitrogen supply in feed to animals' specific protein requirements would decrease the total ammoniacal nitrogen in manure and may decrease feed costs. Similarly, on pasture lands, the proportion of legumes in the stand could be partially managed in order to match nutritional needs. Based on our sensitivity analysis, better management of nitrogen in livestock diets represents the simplest and most effective mitigation strategy and one that can reduce inputs of ammonia to farming systems. By contrast, all the other mitigation measures are designed to reduce losses of ammonia from the systems.

Perhaps the next most beneficial practice would be improved landspreading technology. Emission factors can be decreased from well above 50% to near-zero if manure is not surface spread but is instead injected or rapidly incorporated into the soil. This also saves nitrogen for crop production and may enhance the availability of other nutrients. Finally, there are some techniques for reducing ammonia losses from housing and storage, most of which involve mitigation of odour (e.g. covering manure storage facilities).

It should be kept in mind that these mitigation measures are not necessarily additive. It may not be possible to reduce emissions from all stages of manure handling. In practice, reducing ammonia emissions at one stage may actually lead to larger relative emissions at a later stage. For this reason, it is probably prudent to tie ammonia mitigation strategies to approaches that also preserve the nutrient quality of manure and decrease odour.

■ REFERENCES

Environment Canada and Health Canada, 1999. *Canadian Environmental Protection Act.* http://www.ec.gc.ca/CEPARegistry/gene_info/

Sheppard, S.C., 2002. *Three Approaches to Define the Ecotoxicity Threshold for Atmospheric Ammonia.* Canadian Journal of Soil Science. 82 (3): 341-354.

Sheppard, S.C., S.G. Sommer, and S. Bittman, 2004. *Plan for Developing a Canadian Environmental Indicator for Ammonia Emissions From Agricultural Sources.* Agriculture and Agri-Food Canada, Agassiz (B.C.).

United Nations Economic Commission for Europe (UNECE), 1999. *Protocol to Abate Acidification, Eutrophication and Ground-level Ozone.* UNECD, Gothenburg (Sweden). http://www.unece.org/env/lrtap/multi_h1.htm

23. Particulate Matter

AUTHORS:

G. Edwards
and E. Pattey

INDICATOR NAME:

Agricultural Particulate Matter Emissions Indicator

STATUS:

Currently under development

SUMMARY

The emission of particulate matter (PM) from agricultural operations is an emerging air quality issue in the agriculture sector today. Ambient PM has been linked to negative impacts on human and animal health and on the environment. Even without a complete inventory of emissions, we know that the sector is responsible for a significant share of the total particulate matter generated by anthropogenic, or human, sources. An indicator is currently being developed (i.e. the Agricultural Particulate Matter Emissions Indicator, or APMEI) to assess the extent of and trends in agricultural emissions of particulate matter into the atmosphere. APMEI will be used to monitor progress as corrective measures and policies are implemented.

THE ISSUE

"Particulate matter" is the general term used for a mixture of solid particles and liquid droplets found in the air. Some particles are large enough to be seen as dust or dirt, while others are so small they can be detected only with an electron microscope. "Total Suspended Particulate (TSP)" describes the particulate loading of the atmosphere, representing all PM sizes less than 100 µm. PM_{10} refers to particles that are less than 10 µm, $PM_{2.5}$ describes particles that are smaller than 2.5 µm in diameter. $PM_{2.5}$ emissions are the most problematic of PM emissions, as these particles can travel long distances and can cause the most harm. Particulate matter is also referred to as "primary" or "secondary" depending on its origin. Primary particles, such as dust from roads or black carbon (soot) from combustion sources, are emitted directly into the atmosphere. Secondary particles are formed in the atmosphere from primary gaseous emissions. Secondary PM from agricultural emissions of ammonia makes up a significant part of the total $PM_{2.5}$ emission to the atmosphere.

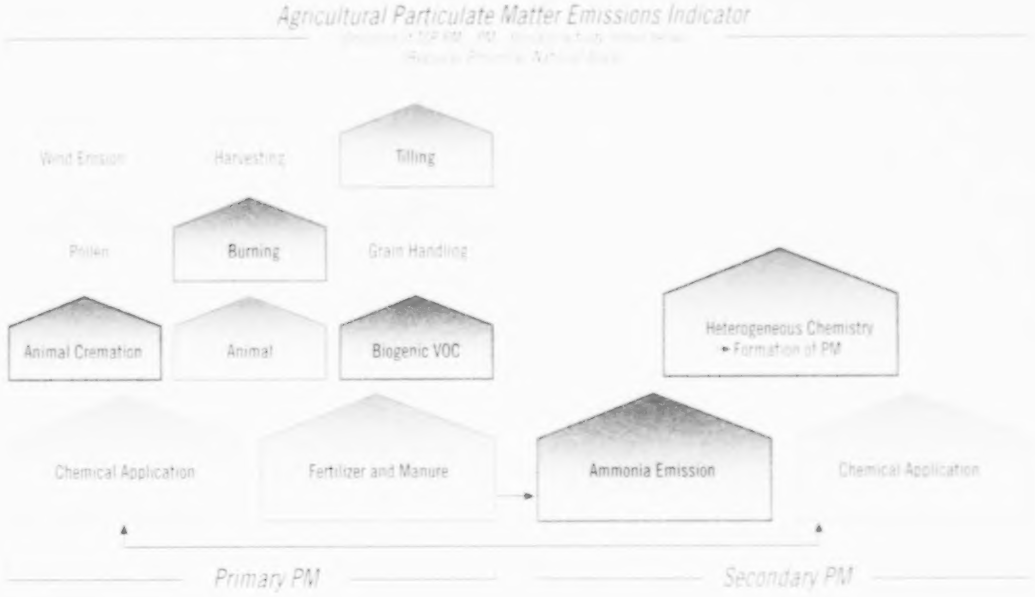
Numerous epidemiological studies worldwide have shown a positive link between ambient PM concentrations and adverse health effects (Lippmann 1998), such as increased bronchodilator use (Pope 1991), bronchitis and chronic coughs in children (Dockery et al. 1989). Particulate matter may be harmful due to the particles' chemical and/or physical characteristics; the particles may also interfere with mechanisms in the respiratory tract; or they may act as a carrier for some other harmful substance. The potential environmental impacts of ambient PM include climate change, decreased visibility, stratospheric ozone depletion and air pollution (e.g. acid rain, smog).

There are many anthropogenic sources of PM, including agricultural sources. The current emissions inventory for Canada indicates that agriculture contributes a significant portion of the particulate matter that is released to the atmosphere, (13% of the TSP, 20% of the PM_{10} and 15% of the $PM_{2.5}$). At present, this inventory does not take into account other known sources of agricultural emissions, such as animal feeding facilities, agricultural burning, or secondary PM created from ammonia emissions. Identification of the sources of PM from agricultural operations is an important step towards assessing the impact of these emissions and the implementation/development of agricultural practices that could mitigate their eventual impacts to human and animal health and on the environment.

THE INDICATOR

An Agricultural Particulate Matter Emissions Indicator (APMEI) is currently being developed to estimate the agriculture sector's contribution to the problem of PM emissions and to provide a means of assessing our progress towards mitigating these emissions. Initially the indicator will be reported as annual PM emission at the national scale for each PM class ($PM_{2.5}$, PM_{10}, TSP). The agricultural categories that are covered are presented in Figure 23-1, which illustrates the conceptual framework of the APMEI.

Figure 23-1: Conceptual framework for the Agricultural Particulate Matter Emissions Indicator


Agricultural Particulate Matter Emissions Indicator
Wind Erosion
Harvesting
Tilling
Pollen
Burning
Grain Handling
Animal Cremation
Animal
Biogenic VOC
Heterogeneous Chemistry
Formation of PM
Chemical Application
Fertilizer and Manure
Ammonia Emission
Chemical Application
Primary PM
Secondary PM

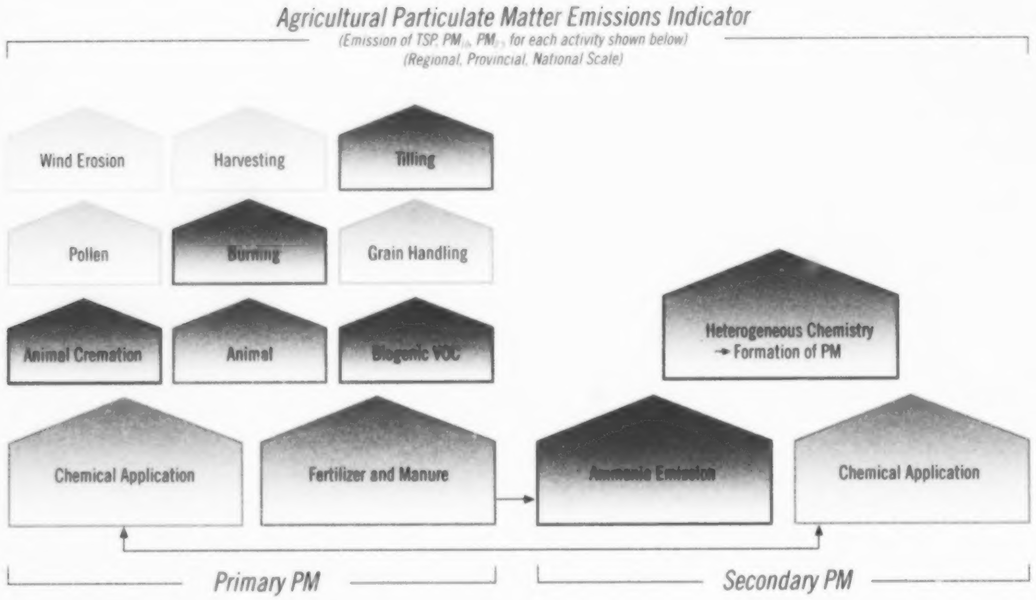
CALCULATION METHOD

The APMEI will be an emission rate (ER), derived from an activity factor (AF) multiplied by an emission factor (EF). Canadian source data (AF), where available, will be used and coupled with emission factors obtained from the literature on this topic, largely U.S. and European studies. Over time, as Canadian EF data become available, the indicator will be adjusted and enhanced to provide a more representative picture of Canadian emissions. The emission factor will typically be expressed as a mass of PM emitted to the atmosphere over a given time period, for each activity unit (e.g. per animal or per square metre) of the emitter. Once the emission factor and the activity level are established for each agricultural source, an estimate can be made of the annual PM emission from Canadian agriculture to the atmosphere.

Over the longer term, it should be possible to produce regional and provincial estimates, in addition to the national-scale estimate. In some circumstances, the scale at which the estimate is reported may be dictated by the zone that is actually affected. For example, the agricultural emissions in an area near a large population centre may be of particular interest. The time scale used for reporting will typically be a year; however, the annual PM emission may in some cases be linked to a particular episode of emissions; hence, the duration of the episode will define the time scale.

The current emissions inventory for Canada indicates that agriculture contributes a significant portion of the particulate matter that is released to the atmosphere.

Figure 23-1: Conceptual framework for the Agricultural Particulate Matter Emissions Indicator


Agricultural Particulate Matter Emissions Indicator
(Emission of TSP, PM_{10}, $PM_{2.5}$ for each activity shown below)
(Regional, Provincial, National Scale)
Wind Erosion
Harvesting
Tilling
Pollen
Burning
Grain Handling
Animal Cremation
Animal
Biogenic VOC
Heterogeneous Chemistry → Formation of PM
Chemical Application
Fertilizer and Manure
Ammonia Emission
Chemical Application
Primary PM
Secondary PM

■ CALCULATION METHOD

The APMEI will be an emission rate (ER), derived from an activity factor (AF) multiplied by an emission factor (EF). Canadian source data (AF), where available, will be used and coupled with emission factors obtained from the literature on this topic, largely U.S. and European studies. Over time, as Canadian EF data become available, the indicator will be adjusted and enhanced to provide a more representative picture of Canadian emissions. The emission factor will typically be expressed as a mass of PM emitted to the atmosphere over a given time period, for each activity unit (e.g. per animal or per square metre) of the emitter. Once the emission factor and the activity level are established for each agricultural source, an estimate can be made of the annual PM emission from Canadian agriculture to the atmosphere.

Over the longer term, it should be possible to produce regional and provincial estimates, in addition to the national-scale estimate. In some circumstances, the scale at which the estimate is reported may be dictated by the zone that is actually affected. For example, the agricultural emissions in an area near a large population centre may be of particular interest. The time scale used for reporting will typically be a year; however, the annual PM emission may in some cases be linked to a particular episode of emissions; hence, the duration of the episode will define the time scale.

The current emissions inventory for Canada indicates that agriculture contributes a significant portion of the particulate matter that is released to the atmosphere.

LIMITATIONS

The main limitation of this approach relates to the availability and accuracy of Canadian emission factors. In some cases, emission factors can be obtained from other countries such as the United States and European countries, while in other cases there may be none available. Furthermore, the activity data that are needed for the indicator calculations may not always be available at the desired temporal and spatial scales. In the longer term, the required data should become available, thus allowing us to provide an increasingly accurate portrait of Canadian emissions and to develop regional estimates and evaluate episodic releases.

RESULTS

This indicator is currently under development and results are not yet available.

RESPONSE OPTIONS

Environmental policies are already in place to deal with PM emissions to the atmosphere from industrial sources, and policy coverage is likely to be extended to the agricultural sector in future. While the Agricultural Particulate Matter Emissions Indicator will initially be developed using a simplified approach, it will nevertheless yield useful preliminary information on particulate matter emissions in the agriculture sector. It will also guide decision makers with respect to the development, implementation and follow-up evaluation of beneficial management practices (BMPs) that can play a role in mitigating PM emissions, such as the following:

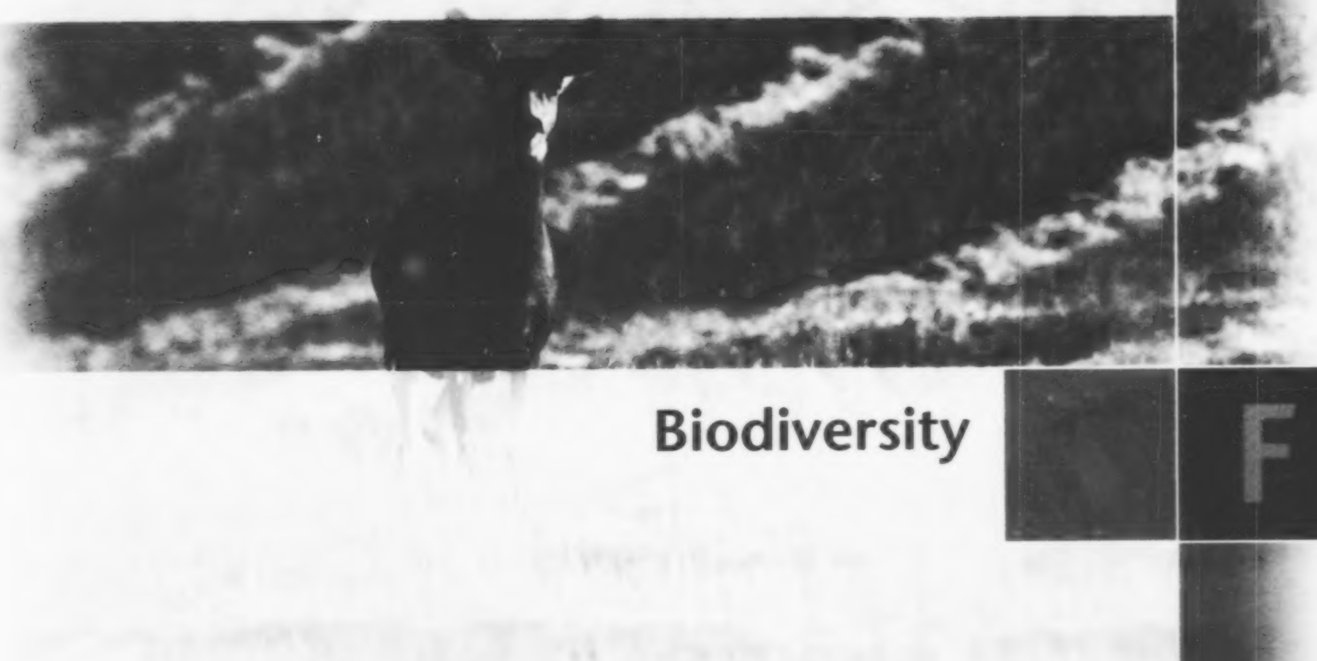
- the installation of dust extraction or ventilation systems in agricultural buildings, with filters and dust-capturing systems;
- the use of mist and water sprinkling to reduce dust in the air (small water particles encapsulate the dust particles, causing them to fall to the floor);
- the use of dust-binding components in feed and bedding material;
- the use of leak-proof ducts and enclosed conveyor systems for grains and feed to prevent particle release; and
- the use of windbreaks to control dust and odour emissions from animal buildings, as well as pollen and other particulate matter from fields.

REFERENCES

Dockery, D.W., F.E. Speizer, D.O. Stram, J.H. Ware, J.D. Spengler, and B.G. Ferris, Jr., 1989. *Effects of inhaled particles on respiratory health of children*. American Review of Respiratory Disease. 139: 587-594.

Lippmann, M., 1998. *Background on health effects of acid aerosols*. Environmental Health Perspectives. 79 : 3-6.

Pope, C.A., 1991. *Respiratory hospital emissions associated with PM10 pollution in Utah, Salt Lake, and Cache valleys*. Archives of Environmental Health. 46: 89-97.



Biodiversity

F

24. Wildlife Habitat on Farmland

AUTHORS:
S.K. Javorek, R. Antonowitsch, C. Callaghan, M. Grant and T. Weins

INDICATOR NAME:
Wildlife Habitat on Farmland Indicator

STATUS:
National coverage, 1981 to 2001

■ SUMMARY

Agricultural land makes a significant contribution to biodiversity. The varied habitats associated with agricultural land provide some or all of the requirements of many wildlife species across Canada. Not all habitat types are equal, however, in their capacity to support wildlife. Wetlands, woodlots, riparian areas and natural pasture are the most important habitat elements for wildlife in the agricultural landscape. The Wildlife Habitat on Farmland Indicator reported on here provides insight into the trends in wildlife habitat available on agricultural land in Canada. The indicator, by associating land area, land use and wildlife use (habitat capacity), improves our understanding of how sectoral, market and policy issues can affect the availability of wildlife habitat on agricultural lands.

The habitat capacity of farmland decreased in Canada between 1981 and 2001. The agricultural intensification that has occurred in some areas of the country since 1981 has caused a decrease in wildlife habitat capacity. In Eastern Canada, for example, increases in cropland have been a driving force in the reduction of wildlife habitat capacity, especially where these increases occurred at the expense of more valuable habitats such as natural pasture, wetlands and woodlands. There have also been some positive changes for wildlife, primarily in Western Canada, through a reduction in the use of summerfallow as part of the crop rotation. Canadian agricultural producers play a primary role in maintaining wildlife habitat capacity through their activities and their decisions. Substantial benefits to biodiversity are realized when producers sustain natural habitats or adopt beneficial management practices that can enhance habitat quality without reducing productivity.

■ THE ISSUE

Agricultural productivity depends on wise, or sustainable, use of resources, including soil, water, energy and nutrients. Similarly, the conservation of biodiversity depends on the wise and sustainable management of the habitats on which all species rely for their continued existence. A suitable wildlife habitat must contain specific components that are critical for wildlife survival: food, water, shelter and space. It must also provide for needs such as reproduction, dispersal and migration. Landscapes lacking wildlife habitats of sufficient quality or in sufficient quantity cannot sustain populations of certain species.

Agricultural land, which makes up 7.5% of Canada's land mass, has the most fertile soils and the most favourable climatic conditions. Canada's agricultural landscape is comprised of cultivated areas and grazing land with associated riparian land, wetlands, woodlands and natural grasslands. These habitats support many of Canada's wildlife species. Over 500 resident or visiting species of birds, mammals, reptiles and amphibians are known to use agricultural lands in Canada. In addition, approximately half of the terrestrial vertebrates currently listed as species at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2004) occur on agricultural lands in Canada. The existence and viability of these species within the agricultural landscape depend on their ability to obtain the necessary resources for breeding, feeding and cover. These resources must be available to the species on the agricultural land itself, or on adjacent habitats within their normal home range. As land managers, agricultural producers play a significant role in sustaining biodiversity.

■ THE INDICATOR

The Wildlife Habitat on Farmland Indicator is used to assess trends in the capacity of agricultural lands to provide suitable habitat that will sustain populations of wild terrestrial vertebrates. The indicator relates the various habitats used by birds, mammals, reptiles and amphibians to five broad land cover categories (habitat types) used in the Census of Agriculture: cropland, summerfallow, tame pasture, natural pasture and *"all other land"*.

Habitat capacity was calculated for these five land cover types at the Soil Landscapes of Canada (SLC) polygon scale, for each of the Census years between 1981 and 2001. The indicator results are expressed in five classes of change in farmland wildlife habitat capacity between different Census years. These classes are defined as follows: large increase (>10%), moderate increase (>2.5% to 10%), negligible to small change (-2.5% to + 2.5%), moderate decrease (<-2.5% to -10%) and large decrease (<-10%). The performance objective for the indicator is for agricultural land to fall in the first two classes, meaning that agro-ecosystems would improve their capacity to provide habitat for wildlife.

■ CALCULATION METHOD

Habitat suitability matrices were previously developed for 493 wildlife species associated with farmland habitat (Neave and Neave 1998). The species list was compiled using information from authoritative wildlife guidebooks, and habitat use information was gathered from a literature review and expert opinion. A matrix was constructed for each terrestrial vertebrate species (bird, mammal, amphibian and reptile) known to use agricultural land and adjacent habitats in Canada for one or more specific habitat requirements (breeding, feeding, loafing, cover, staging and wintering). Each habitat use was ranked as primary, secondary or tertiary according to the importance of the habitat to the species.

As already mentioned, the five broad land cover (agricultural habitat) types in the habitat suitability matrices correspond to five categories of agricultural land found in the Census of Agriculture: cropland, summerfallow, tame pasture, natural pasture and "all other land". These broad categories have been subdivided to more precisely reflect the different habitats found on agricultural land. For example, natural pasture is divided into natural grassland, sagebrush/shrubs and shrubs/woodland. A Habitat Capacity Index is calculated by relating the number of species that use each of the five selected land cover categories to the relative area occupied by each land cover type. Only primary and secondary habitat use for breeding, feeding or cover is considered in the calculations. The indicator then assesses the impact of relative changes in land cover types on the wildlife habitat capacity of agricultural land in Canada.

■ LIMITATIONS

The following limitations apply to this indicator:

- Because the "all other land" category from the Census of Agriculture does not currently capture the area or changes in some habitat types that are important to wildlife (e.g. wetlands and woodlands), the trends in these habitats cannot be adequately differentiated in the indicator calculations.

- The indicator does not currently capture measures of habitat quality (e.g. fragmentation, connectivity, spatial configuration, forest interior habitat) except through the inclusion of primary and secondary habitat uses in the analysis. Smaller-scale studies have been set up to address this information gap and support future reporting.

- The indicator is currently unable to reflect the beneficial effects on wildlife habitat that are associated with some management practices, such as rotational and complementary grazing systems or conservation tillage.

- In its current form, the indicator only reflects habitat capacity for terrestrial vertebrates. It does not consider other elements of biodiversity, such as plants, aquatic animals or invertebrates, that could be affected by agriculture.

- The categories used to assess change in wildlife habitat capacity (five classes) were chosen subjectively. No methodology was found that could be used to objectively display a meaningful amount of increase or decrease in habitat capacity. Error margins in the data should be incorporated into future iterations of the indicator.

- The indicator does not currently relate changes in the wildlife habitat capacity of agricultural land to an actual response (increase or decrease) by wildlife populations.

Table 24-1: Wildlife habitat capacity of farmland in Canada, 1981 to 2001

Share of farmland in various classes of change in wildlife habitat capacity (in %)

	20-year trend (1981 to 2001)					10-year trend (1991 to 2001)				
Province	large increase	moderate increase	negligible to small change	moderate decrease	large decrease	large increase	moderate increase	negligible to small change	moderate decrease	large decrease
	>10%	>2.5% to 10%	-2.49 to 2.49	<-2.5% to -10%	< -10%	>10%	>2.5% to 10%	-2.49 to 2.49	<-2.5% to -10%	< -10%
BC	2	10	39	39	11	1	2	8	56	33
AB	1	13	59	26	1	<1	1	11	84	4
SK	<1	35	55	9	<1	<1	<1	8	87	5
MB	0	7	75	17	1	1	2	33	63	1
ON	0	<1	5	92	2	0	<1	2	56	42
QC	<1	<1	1	62	37	<1	1	8	54	37
NB	<1	1	12	69	18	1	4	28	50	17
NS	<1	<1	12	69	19	1	7	33	50	9
PEI	0	0	0	94	6	0	0	40	53	7
NL	1	11	22	60	6	2	11	14	47	26
Canada	**<1**	**19**	**51**	**27**	**3**	**<1**	**1**	**12**	**77**	**10**

■ RESULTS

Table 24-1 shows the changes in the Wildlife Habitat on Farmland Indicator for two periods: a 10-year period (1991-2001) and a 20-year period (1981-2001). Twenty-year habitat capacity trends are represented on the maps in Figure 24-1 and discussed below.

Canada: Between 1981 and 2001, the majority (51%) of agricultural land across Canada showed negligible to small changes in habitat capacity. Moderate increases were observed on 19% of farmland, thus 19% of farmland met the desired performance objective for this indicator. Moderate and large decreases were however observed on 27% and 3% of farmland respectively.

British Columbia: Wildlife habitat capacity decreased on 50% of farmland (moderate: 39%, large: 11%) from 1981 to 2001. Negligible to small changes occurred on 39% of farmland, while wildlife habitat capacity increased on 12% of farmland (moderate: 10%, large: 2%).

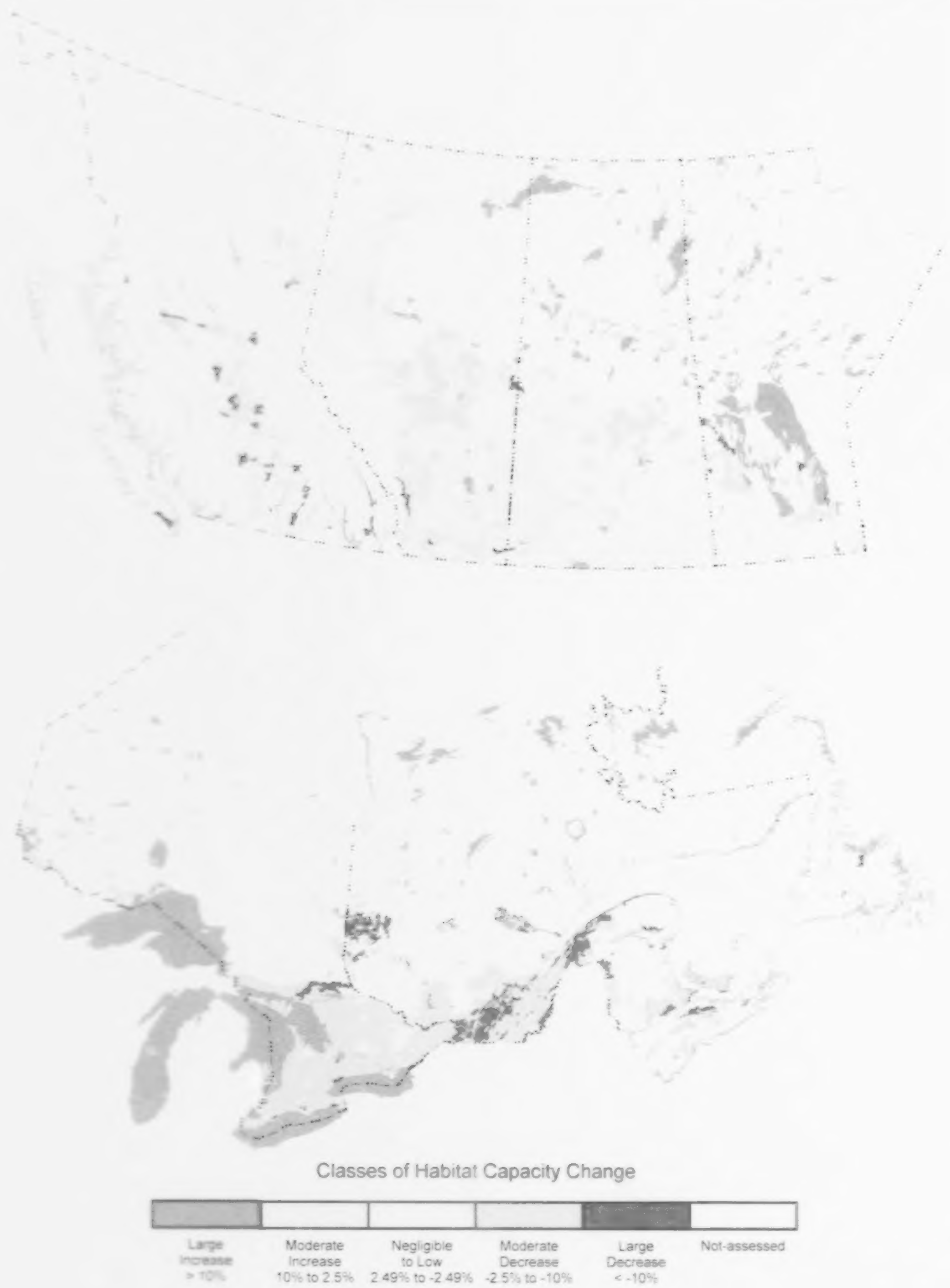
Alberta: Negligible to small changes in wildlife habitat capacity occurred on 59% of farmland from 1981 to 2001. Wildlife habitat capacity decreased on 27% of farmland (moderate: 26%, large: 1%) and increased on 14% of farmland (moderate: 13%, large: 1%).

Saskatchewan: Negligible to small changes in wildlife habitat capacity occurred on 55% of farmland from 1981 to 2001. Wildlife habitat capacity increased on 35% of agricultural land (moderate) and decreased on 9% of farmland (moderate).

Manitoba: Negligible to small changes in wildlife habitat capacity occurred on 75% of farmland from 1981 to 2001. Wildlife habitat capacity decreased on 18% of farmland (moderate: 17%, large 1%) and increased on 7% of farmland (moderate).

Ontario: Wildlife habitat capacity decreased on 94% of farmland (moderate: 92%, large: 2%) from 1981 to 2001. Negligible to small changes occurred on 5% of farmland.

Figure 24-1: Change in wildlife habitat capacity on Canadian farmland between 1981 and 2001


Classes of Habitat Capacity Change
Large Increase > 10%
Moderate Increase 10% to 2.5%
Negligible to Low 2.49% to -2.49%
Moderate Decrease -2.5% to -10%
Large Decrease < -10%
Not-assessed

Quebec: Wildlife habitat capacity decreased on 99% of farmland (moderate: 62%; large: 37%) from 1981 to 2001. Negligible to small changes occurred on 1% of farmland.

New Brunswick: Habitat capacity decreased on 88% of farmland (moderate: 69%, large 19%) from 1981 to 2001. Negligible to small changes occurred on 12% of farmland.

Nova Scotia: Wildlife habitat capacity decreased on 87% of farmland (moderate: 69%, large 18%) from 1981 to 2001, while negligible to small changes occurred on 12% of farmland.

Prince Edward Island: Habitat capacity decreased on all farmland (moderate: 94%, large: 6%).

Newfoundland and Labrador: Negligible to small changes in habitat capacity occurred on 22% of agricultural land. Habitat capacity decreased on 66% of farmland (moderate: 60%, large: 6%) and increased on 12% of farmland (moderate: 11%, large: 1%).

■ INTERPRETATION

Canada: Between 1981 and 2001, wildlife habitat capacity decreased by 5% on Canada's agricultural land. The driving forces for this national decrease appear to have been an expansion in the relative percentage of cropland, from 47% to 53% of all farmland, and a 3% decline in species-rich natural pasture. Although there were some improvements in wildlife habitat trends, they did not completely offset the declines. For example, the most important land-cover Census category for wildlife—"all other land"—increased its share of the national agricultural landscape from 6% to 9%. Another important trend was a reduction (from 15% to 7%) in the species-impoverished summerfallow habitat as a proportion of Canadian farmland. During this 20-year period, the relative percentage of *tame pasture* remained stable at 7% even though agricultural permanent cover programs from 1989 to 1993 resulted in the conversion of about half a million hectares of marginal cropland on the Prairies to tame forages.

British Columbia: There are currently 331 wildlife species using agricultural land in British Columbia. Between 1981 and 2001, habitat capacity decreased by less than 2%. Although farmland increased by 19%, there were only minor shifts in the relative percentages of habitat types. Negative trends influencing the slight provincial decline in habitat capacity were a 2% drop in the relative share of farmland occupied by species-rich natural pasture and a decline in the relative percentage of tame pasture (from 12% to 9%). These negative trends were generally counterbalanced by an increase in the relative share of "all other land".

Alberta: There are 337 wildlife species known to use agricultural land in Alberta. Between 1981 and 2001, habitat capacity decreased by less than 1%. During this period, farmland expanded by 10%, resulting in minor shifts in the relative percentages of the five habitat categories. The positive shifts consisted of a relative increase in "all other land" (from 4% to 6%) and a reduction of summerfallow (from 11% to 6%). The negative shifts consisted of a relative expansion of cropland (from 44% to 46%); and a drop in tame pasture (from 10% to 8%). Due in part to the expansion of farmland, natural pasture reportedly increased by 10% but most of this increase can likely be attributed to a difference in the Census questions between 1981 and 2001. Natural pasture's relative share of the agricultural landscape remained constant.

Saskatchewan: There are about 290 wildlife species known to use agricultural land in Saskatchewan. This was the only province to post an overall increase in habitat capacity (1%) between 1981 and 2001. This resulted from an increase in "all other land" from 2% to 5% of farmland and a significant reduction in the relative proportion of summerfallow (from 26% to 12%). These positive trends were slightly stronger than the negative trends, which included an expansion of cropland (from 45% to 59%) and a reduction in natural pasture (from 23% to 20%).

Manitoba: Agricultural land in Manitoba provides habitat for 311 wildlife species. Between 1981 and 2001, habitat capacity declined by less than 1%. There were two counterbalancing trends that resulted in fairly stable habitat capacity at the provincial scale. The negative trend essentially resulted from the expansion of cropland (from 58% to 62%). Natural pasture remained constant (in relative terms). The positive trends were an increase in "all other land" from 5% to 9% of farmland and a reduction in summerfallow (from 8% to 3%).

Ontario: Currently, there are 281 wildlife species known to use agricultural land in Ontario. Between 1981 and 2001, 9% of farmland was converted to other land uses. This resulted in a 6% decline in habitat capacity, explained by an increase in the relative percentage of cropland (from 60% to 67%), a decrease in natural pasture (from 13% to 9%) and a decrease in tame pasture (from 11% to 6%). During this period there was a slight increase in "all other land" (15% to 17% of agricultural land cover).

Quebec: There are currently 274 wildlife species that use agricultural land in Quebec. The primary driving force behind the observed 10% decline in wildlife habitat capacity was a drop in the important wildlife habitat provided by natural pasture (5% reduction or 163,000 hectares) and by tame pasture (from 13% to 9%, a 260,000-hectare drop). The relative amount of cropland increased from 46% to 54%. The percentage of "all other land" stayed relatively constant.

> *Between 1981 and 2001, wildlife habitat capacity decreased by 5% on Canada's agricultural land.*

Nova Scotia: A total of 184 wildlife species are currently known to use agricultural land in Nova Scotia. The main driving force behind the habitat capacity decrease was the expansion of cropland (from 24% to 31% of farmland) accompanied by a reduction in natural pasture (from 10% to 7%) and tame pasture (from 9% to 5%). The relative percentage of "all other land" remained constant.

New Brunswick: A total of 197 wildlife species currently use agricultural land in New Brunswick. Although agricultural land cover decreased by 11% in the province between 1981 and 2001, cropland increased from 30% to 39% of farmland and natural pasture decreased from 10% to 7%. Tame pasture also decreased from 9% to 5% of farmland. The relative percentage of "all other land" remained constant.

Prince Edward Island: There are currently 174 wildlife species that use habitat within the agricultural landscape of Prince Edward Island. Habitat capacity of farmland decreased by 12% between 1981 and 2001. Although farmland declined by 7%, the actual percentage of cropland increased from 56% to 67%. This resulted in a decrease in "all other land" (from 25% to 23%) and in tame pasture (from 13% to 5%). The relative percentage of natural pasture remained stable.

Newfoundland and Labrador: Given the relatively small percentage of agricultural land cover, agriculture can be expected to have minimal effects on wildlife at the provincial scale. A total of 214 wildlife species have been reported to use farmland. The expansion of farmland and the resulting major redistribution of cover types led to an overall decrease in habitat capacity (6%) between 1981 and 2001. The major cause of this reduction was the increase in the relative proportion of cropland (from 14% to 21%).

■ RESPONSE OPTIONS

Agricultural producers, as land managers, play a significant role in sustaining biodiversity. The land use and management decisions they make can adversely affect wildlife habitat (e.g. wetland drainage, *overgrazing*, removing or fragmenting forest cover). Management practices can also have positive effects on wildlife, either by augmenting habitat quality or quantity or by increasing the connectivity between habitat patches.

Maintaining or increasing the wildlife habitat capacity of agricultural land requires a thoughtful approach and a clear sense of how it can be done without diminishing agricultural productivity. This information is best gathered regionally and locally, where planners can work with landowners to set habitat goals and objectives that meet the needs of species. Most farmers understand the value of conserving wildlife and wildlife habitat, but education and incentive programs can further this understanding and encourage the voluntary participation of landowners in implementing land management practices that favour wildlife. Such beneficial management practices include:

- Developing and implementing an Environmental Farm Plan
- Conserving remaining natural (native) lands (grasslands, wetlands, woodlands)
- Conserving riparian areas (buffer strips)
- Adopting conservation tillage systems
- Delayed haying and grazing
- Winter cover cropping
- Implementing rotational grazing systems
- Integrated pest management
- Woodlot management
- Planting shelterbelts and hedgerows in appropriate landscapes
- Converting marginal cropland to permanent cover
- Preventing wildlife damage.

REFERENCES

Committee on the Status of Endangered Wildlife in Canada (COSEWIC), 2004. *Canadian Species at Risk*. COSEWIC, Ottawa (Ont.). http://www.cosewic.gc.ca/eng/sct0/sar_2004_11_e.cfm

Cox, K.W., 1993. *Wetlands: a Celebration of Life* – Final Report of the Canadian Wetlands Conservation Task Force. Sustaining Wetlands Issues Paper Series, No. 1993-1. North American Wetlands Conservation Council [Canada], Ottawa (Ont.).

Federal-Provincial-Territorial Biodiversity Working Group, 1995. *Canadian Biodiversity Strategy. Canada's Response to the Convention on Biological Diversity*. Environment Canada, Biodiversity Convention Office, Ottawa (Ont.). http://www.eman-rese.ca/eman/reports/publications/rt_biostrat/intro.html

Neave, P., and E. Neave, 1998. *Habitat and Habitat Availability Indicator*. Report produced for Agriculture and Agri-Food Canada's Agri-Environmental Indicator Project. Agriculture and Agri-Food Canada, Ottawa (Ont.).

Watmough, M.D., D.W. Ingstrup, D.C. Duncan and H.J. Schinke, 2002. *Prairie Habitat Joint Venture Monitoring Program Phase I: Recent Habitat Trends in NAWMP Targeted Landscapes* (Technical Report Series No. 391). Environment Canada, Canadian Wildlife Service, Edmonton (Alberta).

25. Wildlife Damage to Crops and Livestock

SUMMARY

The Risk of Wildlife Damage (RWD) Indicator is currently being developed to gain a better understanding of the biophysical and management factors that influence wildlife damage to agricultural products across Canada. This tool will also help us assess whether the actual risk of wildlife damage is increasing, decreasing or remaining stable, in each province. Creation of the Risk of Wildlife Damage Indicator entails the development of predictive models of damage risk that harness crop-yield loss data and spatial information on key factors known to influence the severity of wildlife damage, such as weather events, cropping practices, mitigation efforts, proximity of wildlife habitat and wildlife population status. Risk models, historical data and small-scale farm surveys will be used to plot recent trends in wildlife damage and predict the changes that may occur in the trends following the adoption of damage prevention measures.

AUTHORS:

D. Thompson,
C. Callaghan,
L. Liggins and
T. Weins

INDICATOR NAME:

Risk of Wildlife Damage Indicator

STATUS:

Currently under development

THE ISSUE

Canadians appreciate the aesthetic, recreational, subsistence, intrinsic and ecological values of wildlife, and maintaining wildlife populations is a major environmental priority in Canada (Federal-Provincial-Territorial Task Force on the importance of Nature to Canadians 2000). At the same time, there is a growing realization that the creation of conservation areas such as parks, wildlife management areas and forest reserves does not provide sufficient habitat to maintain desired wildlife populations. Agricultural land has the most fertile soils with the most favourable *microclimates* in the country and historically has supported many of Canada's wildlife species. Even today, many wildlife species continue to use farmland to meet their needs.

Agricultural producers across Canada enjoy living in proximity to wildlife and natural areas and recognize the importance of wildlife as much as other Canadians. Many of them invest time and money to enhance wildlife habitat on their land (Environics Research Group 2000). However, interactions between wildlife and agricultural activities can at times result in severe damage to agricultural products. Most wildlife species have a benign or even beneficial effect on agriculture (e.g. songbirds and raptors help control pests), but the relatively few species that feed on crops, stored feed or livestock can cause yield losses, livestock losses and damage to farm property. For example, deer and elk damage field (e.g. corn, alfalfa, soybean) and horticultural crops, as well as haystacks; waterfowl damage various crops (e.g. wheat, barley, lentils); birds such as starlings and blackbirds damage fruit crops; and some carnivores kill livestock. Wildlife damage on agricultural land is most often caused by wildlife species that are not at risk and may actually be abundant (Conover 2002).

Although most producers tolerate some risk of damage in their daily operations, the actual level, predictability, extent and cause of wildlife damage vary widely among the provinces, farming regions and individual farms, as well as from year to year. In a survey conducted in 2000, 57% of rural landowners interviewed across Canada said that they had at some point experienced this type of damage in their operations. Many believe that wildlife activity and damage are on the rise (Environics Research Group 2000).

THE INDICATOR

The Risk of Wildlife Damage Indicator will be a tool for identifying the biophysical and management factors that influence the risk of wildlife damage to agriculture, modelling their relationships and determining whether the risk of damage is increasing, decreasing or remaining static over time. This risk can be expressed as a functional relationship between biophysical factors (weather conditions, density and distribution of problem species, availability of off-farm and on-farm habitat), management factors (damage reduction efforts, type of production and the use of beneficial management practices) and occurrence of damage (Figure 25-1).

■ CALCULATION METHOD

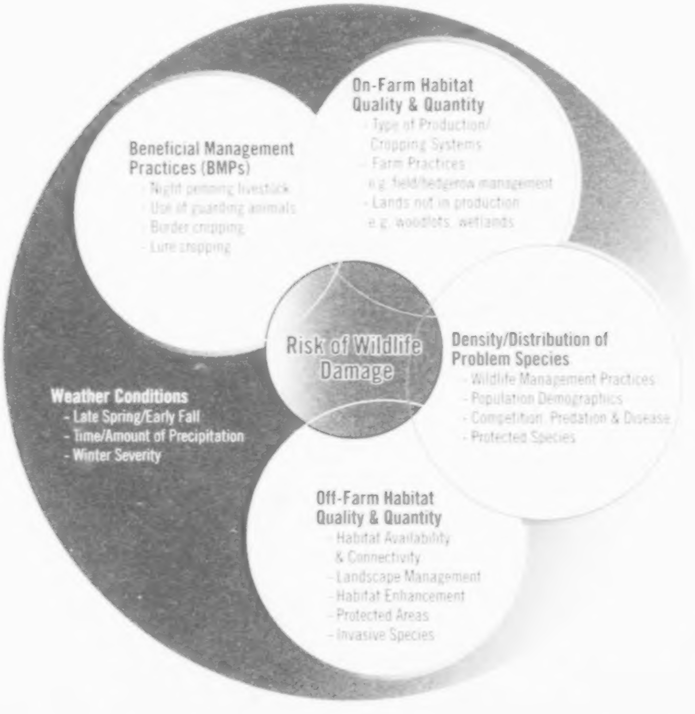
The biophysical factors influencing wildlife damage are likely too complex and regionally variable to be integrated into a single model that would accurately or precisely estimate the amount of wildlife damage expected to occur in every region of Canada. Therefore, a series of wildlife damage risk models will be developed using damage data for specific wildlife classes (e.g., waterfowl, ungulates [such as deer], and predators) in several regions across Canada.

Spatial data on biophysical factors and data from existing wildlife damage records or small-scale surveys of producers will be gathered to build the models. Then, statistical analyses will be performed to determine the relative importance of each variable to the overall risk of wildlife damage and to rank the expected frequency of damage for a prescribed geographic area. Independent damage occurrence data and/or expert opinions will be used to validate the provincial-scale results.

■ LIMITATIONS

With this indicator, damage risk assessment will be limited to wildlife such as ungulates, waterfowl, and predators, which are species that have historically been the focus of mitigation and compensation programs and a concern for producers and provincial wildlife managers. Initially, the Risk of Wildlife Damage Indicator will not address crop losses caused by invasive species or disease transmission between livestock and wildlife. It also will not cover crop damage caused by insects or rodents, although they may consume much more crop *biomass* than the waterfowl or ungulates. These components may be incorporated into a future version of the indicator.

Figure 25-1: Conceptual model showing relationship among biophysical and management factors influencing the risk of wildlife damage


On-Farm Habitat
Quality & Quantity
- Type of Production/
Cropping Systems
- Farm Practices
e.g. field/hedgerow management
- Lands not in production
e.g. woodlots, wetlands
Beneficial Management
Practices (BMPs)
- Night penning livestock
- Use of guarding animals
- Border cropping
- Lure cropping
Risk of Wildlife
Damage
Density/Distribution of
Problem Species
- Wildlife Management Practices
- Population Demographics
- Competition, Predation & Disease
- Protected Species
Weather Conditions
- Late Spring/Early Fall
- Time/Amount of Precipitation
- Winter Severity
Off-Farm Habitat
Quality & Quantity
- Habitat Availability
& Connectivity
- Landscape Management
- Habitat Enhancement
- Protected Areas
- Invasive Species

distribution of problem species, availability of off-farm and on-farm habitat), management factors (damage reduction efforts, type of production and the use of beneficial management practices) and occurrence of damage (Figure 25-1).

■ CALCULATION METHOD

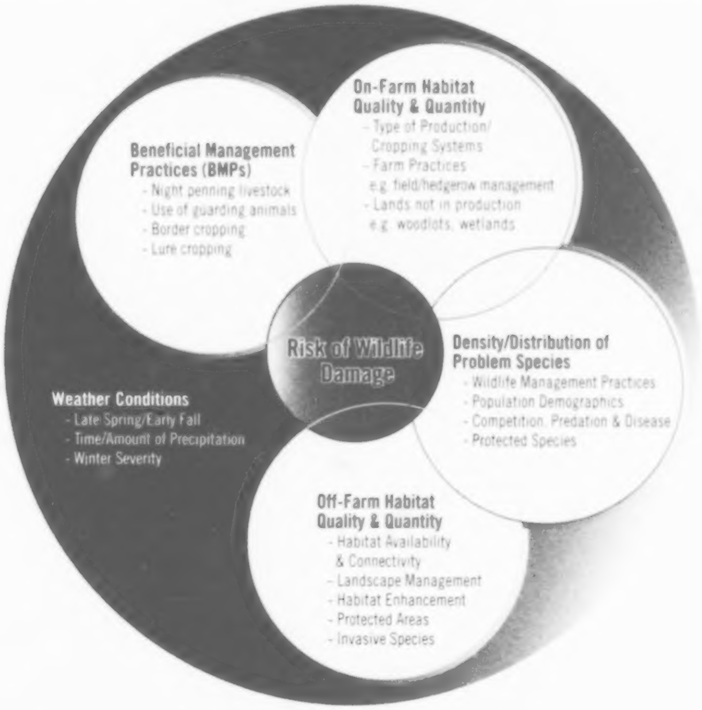
The biophysical factors influencing wildlife damage are likely too complex and regionally variable to be integrated into a single model that would accurately or precisely estimate the amount of wildlife damage expected to occur in every region of Canada. Therefore, a series of wildlife damage risk models will be developed using damage data for specific wildlife classes (e.g., waterfowl, ungulates [such as deer], and predators) in several regions across Canada.

Spatial data on biophysical factors and data from existing wildlife damage records or small-scale surveys of producers will be gathered to build the models. Then, statistical analyses will be performed to determine the relative importance of each variable to the overall risk of wildlife damage and to rank the expected frequency of damage for a prescribed geographic area. Independent damage occurrence data and/or expert opinions will be used to validate the provincial-scale results.

■ LIMITATIONS

With this indicator, damage risk assessment will be limited to wildlife such as ungulates, waterfowl, and predators, which are species that have historically been the focus of mitigation and compensation programs and a concern for producers and provincial wildlife managers. Initially, the Risk of Wildlife Damage Indicator will not address crop losses caused by invasive species or disease transmission between livestock and wildlife. It also will not cover crop damage caused by insects or rodents, although they may consume much more crop *biomass* than the waterfowl or ungulates. These components may be incorporated into a future version of the indicator.

Figure 25-1: Conceptual model showing relationship among biophysical and management factors influencing the risk of wildlife damage


On-Farm Habitat Quality & Quantity
- Type of Production/ Cropping Systems
- Farm Practices e.g. field/hedgerow management
- Lands not in production e.g. woodlots, wetlands
Beneficial Management Practices (BMPs)
- Night penning livestock
- Use of guarding animals
- Border cropping
- Lure cropping
Risk of Wildlife Damage
Density/Distribution of Problem Species
- Wildlife Management Practices
- Population Demographics
- Competition, Predation & Disease
- Protected Species
Weather Conditions
- Late Spring/Early Fall
- Time/Amount of Precipitation
- Winter Severity
Off-Farm Habitat Quality & Quantity
- Habitat Availability & Connectivity
- Landscape Management
- Habitat Enhancement
- Protected Areas
- Invasive Species

RESULTS

This indicator is currently under development and results are not yet available.

RESPONSE OPTIONS

Socio-economic and political factors influence perceptions of damage and the approaches that are adopted to deal with wildlife damage. Consequently, strategies to reduce wildlife damage on farmland must reflect the diverse facets of the problem and they should be grounded in a broader economical, ecological and sociological context (Reed 1991). In the past, widespread lethal control programs (e.g. kill permits for ducks, poisoning of wolves) were commonly used to reduce wildlife damage to agriculture. However, this approach became increasingly unpalatable to the public, and as societal values changed over time, lethal methods gradually gave way to non-destructive methods. Producers can now lessen the susceptibility of their farms to wildlife damage through a variety of beneficial farm management practices such as production system decisions, habitat management, harvesting practices and damage prevention measures, including:

- fencing or border cropping with unpalatable crops for large ungulates;
- visual and audio scare devices or lure crops for waterfowl;
- the use of husbandry practices such as night penning, calving close to farm;
- use of fencing, buildings and guardian animals to reduce livestock *depredation* by carnivores.

> *The Risk of Wildlife Damage Indicator will be a tool for identifying the biophysical and management factors that influence the risk of wildlife damage to agriculture.*

Wildlife management agencies can also mitigate the susceptibility of farmland to wildlife damage through wildlife and habitat management efforts, targeted lethal control of carnivores and various prevention programs. Given the different damage-causing species and their diverse behavioural and life history characteristics, it is unlikely that any single method of damage prevention can guarantee success. Strategies employing several management techniques in an integrated approach are likely to be the most effective means of reducing damage (Ontario Soil & Crop Improvement Association 2000). Once this indicator comes on stream, it will aid in assessing the effectiveness of management strategies for reducing wildlife damage on agriculture and increase understanding of the factors that influence success.

REFERENCES

Conover, M.R., 2002. *Resolving Human-Wildlife Conflicts: The Science of Wildlife Damage Management*. Lewis Publishers, Boca Raton (Florida).

Environics Research Group, 2000. *Survey of Farmers, Ranchers and Rural Landowners: Attitudes and Behaviours Regarding Land Stewardship*. ERG, Toronto (Ont.).

Federal-Provincial-Territorial Task Force on the Importance of Nature to Canadians, 2000. *The Importance of Nature to Canadians: The Economic Significance of Nature-related Activities*. Environment Canada, Ottawa (Ont.).

Ontario Soil and Crop Improvement Association, 2000. *Wildlife Impact Assessment for Ontario Agriculture*. OSCIA, Guelph (Ont.).

Reed, A., 1991. "*Management of Greater Snow Geese in Relation to Crop Damage: the Need for a Diversified and Integrated Approach*". Pages 93-100 in M. Van Roomen and J. Madsen (eds), Waterfowl and Agriculture: Review and Future Perspective of the Crop Damage Conflict in Europe, proceedings of the 'Farmers and Waterfowl: Conflict or Coexistence' Workshop in Lelystad, Netherlands. Wetlands International, Publication No. 21, Slimbridge (U.K.).

26. Invasive Alien Species

AUTHORS:
P.G. Mason,
R.G. Foottit,
S.I. Warwick
and O. Olfert

INDICATOR NAME:
Risk from Invasive Alien Species

STATUS:
Currently under development

■ SUMMARY

Invasive alien species *have a significant impact on production costs and may even represent a major threat to agricultural production itself. The Indicator of Risk from Invasive Alien Species (IAS) is currently being developed to help assess population trends (population size and distribution) for invasive alien species of significance for agriculture (Table 26-1). It will also be used to provide information on the major threats that these species pose to agroecosystem health and agricultural trade. The IAS risk indicator will be reported for individual species or groups of species on a local, regional or national scale. It will be built using IAS presence and abundance data and an index of* invasiveness. *This information will be combined with spatial data and information on key factors known to influence the distribution of invasive species, including farm management practices.*

■ THE ISSUE

Invasive alien species (IAS) are typically aggressive non-native species that, if left unchecked, will spread and dominate an ecosystem, reduce the *indigenous biodiversity* and, in so doing, disrupt ecosystem functions. They immigrate through various natural pathways (seeds drifting to shore; "hitchhikers" on migrating birds, mammals and insects; spores and arthropod-borne diseases) and through human activities. Increased global trade and travel have exacerbated the problem by creating new opportunities for species introductions.

Agroecosystems, like other ecological systems, require a certain level of biodiversity to maintain their functions. However, agroecosystems also tend to be ecologically simplified (e.g. *monocultures*) and therefore are even more susceptible to invasive alien species than natural systems. Invasive species can therefore contribute to higher production costs and, in some cases, they may inflict a heavy toll on agricultural production itself. Invasive alien species have even triggered trade embargoes under the World Trade Organization (WTO) rules (e.g. potato wart fungus, swede midge) and depressed commodity values (e.g. *Solanum* weeds in soybeans). In fact, a great many of the existing agricultural pests are invasive alien species that were introduced at some point over the last 100 years. Other productivity impacts may result from *hybridization* between non-indigenous and closely related *native species*, disruption of native predators and parasites, reduction in the biodiversity of native species and in their populations, global extinction of native species and changing ecosystem processes.

■ THE INDICATOR

The Indicator of Risk from Invasive Alien Species will aim at assessing trends in population distributions and in numbers of invasive alien species in agricultural habitats, revealing major pressures or threats to agroecosystem health and agricultural trade posed by the following:

1) existing IAS in Canada
2) established alien species with the potential to become invasive
3) known IAS, currently not present in Canada, but with a high potential to invade.

The Indicator of Risk from Invasive Alien Species will be reported as risk classes for individual species or groups of species (for a commodity) on a local, regional or national scale, at a given time. By comparing the indicator results over time, we will be able to determine whether the level of risk is increasing or decreasing as a result of changes in farm management practices, including national trends in the industry (e.g. importation of seeds).

Table 26-1: Examples of Invasive Alien Species of Significance to Canadian Agriculture

Common Name	Scientific Name	Commodity Affected	Area of Origin
Cabbage seedpod weevil	*Ceutorhynchus obstrictus* (Marsham)	canola	Europe
Canada thistle	*Cirsium arvense* (L.) Scopoli	barley, canola, corn, wheat	Eurasia
Codling moth	*Cydia pomonella* (L.)	apples	Eurasia
Colorado potato beetle	*Leptinotarsa decemlineata* (Say)	potato	South America
Crown and root rot	*Phytophthora cactorum* (Lebert and Cohn) Schröter	apple	unknown
Dandelion	*Taraxacum officinale* (Weber)	pastures, forages, orchards, vineyards, vegetable gardens, annual crops	Europe
Crucifer flea beetle, striped flea beetle	*Phyllotreta cruciferae* (Goeze), *Phyllotreta striolata* (F.)	canola	Europe
Leafy spurge	*Euphorbia esula* (L.)	pastures, rangeland	Eurasia
Melon/cotton aphid, foxglove aphid, green peach aphid	*Aphis gossypii* (Glover), *Aulacorthum* solani (Kaltenbach), *Myzus persicae* (Sulzer)	greenhouse crops	
Spotted knapweed, diffuse knapweed	*Centaurea diffusa* Lamarck, *Centaurea maculosa* Lamarck	rangeland, pastures	Eurasia
Wild oat	*Avena fatua* L.	barley, wheat	Eurasia

■ CALCULATION METHOD

The IAS indicator is in the early stages of development but historical and real-time survey data will be used in order to determine IAS presence and abundance. Available taxonomic and ecological information on invasive alien species will be used to generate an index of invasiveness. The IAS risk indicator algorithm will then be built using this information, in combination with spatial data on the distribution of IAS (e.g. from periodic insect and weed surveys) and native species related to them; data on biophysical factors (climate, soil type, landscape); data on land use and land cover; and data on management practices (e.g. pesticide use). It will be reported on various scales (regional, provincial or national).

Agroecosystems also tend to be ecologically simplified and therefore are even more susceptible to invasive alien species than natural systems.

■ LIMITATIONS

The value of any indicator is directly linked to the quality of the data used for calculation purposes. A risk potential can only be assigned if "invasiveness characteristics" are clearly defined. And while a significant number of agricultural pests are invasive alien species and methodology has already been developed to measure changes in the population trends for these species, good biological information on these potential invaders is still limited. Consequently, the characterizations of "invasiveness" will only be estimates. Real-time assessments are possible only if annual area-wide surveys are conducted and there is a base dataset available for comparison.

Ongoing research is required to improve our knowledge and understanding of IAS, including in-depth studies of the biology of selected species to learn more about what makes them invasive, taxonomic studies of groups known to contain IAS, and international surveys to determine the most likely sources of potential invaders and invasion routes.

■ RESULTS

This indicator is currently under development and results are not yet available.

■ RESPONSE OPTIONS

Producers can strive to reduce the pressure exerted by invasive alien species and improve the health of the agricultural environment by adopting beneficial management practices such as conserving habitats that enhance indigenous biodiversity; minimizing habitat disruption (e.g. minimum tillage); applying biologically based integrated pest management approaches (e.g. cultivars resistant to IAS) and using biological control agents that specifically target invasive alien species.

■ REFERENCES

Hallman, G.J. and C.P. Schwalbe (eds), 2002. *Invasive Arthropods in Agriculture: Problems and Solutions*. Science Publishers Inc. Enfield (New Hampshire).

National Research Council (NRC), 2002. *Predicting Invasions of Nonindigenous Plants and Plant Pests*. NRC, Committee on the Scientific Basis for Predicting the Invasive Potential of Nonindigenous Plants and Plant Pests in the United States. National Academy Press, Washington (D.C.).

Pimentel, D. (ed.), 2002. *Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species*. CRC Press, Boca Raton (Florida).

27. Soil Biodiversity

SUMMARY

Soil organisms are an essential component of agroecosystems, making vital contributions to soil functions and soil processes. Without soil organisms, the soil would be a sterile medium that could not sustain crop production. A Soil Biodiversity Indicator is currently being developed to provide a framework for assessing how various environmental and anthropogenic factors, including land use and agricultural management practices, affect the habitats of soil biota *and their potential population abundance. How these populations respond can affect soil functions that are required for optimal crop growth.*

AUTHOR:
C.A. Fox

INDICATOR NAME:
Soil Biodiversity Indicator

STATUS:
Currently under development

THE ISSUE

Living organisms in the soil—or soil biota—provide essential benefits for the functioning of agroecosystems which are vital for the long-term sustainability of agriculture. They support essential soil processes and play a key role in maintaining the soil quality that is necessary for crop productivity. Soil organisms help to create and maintain beneficial soil structure; suppress soil pathogens and pests; aid in breaking up and decomposing crop residues so that valuable nutrients are released for plant growth; contribute to soil carbon storage by mixing organic materials with mineral soil; and facilitate the breakdown of chemicals and amendments added to the soil (Brussard et al. 1997, Altieri 1999).

Soil biota populations respond to the physical, chemical and biological characteristics of their environment in addition to the various natural and anthropogenic (human-induced) pressures or stresses acting on the soil ecosystem (Fox and MacDonald 2003). Environmental stressors may include soil erosion, loss of soil organic matter and climate change that affects temperature and moisture regimes. Anthropogenic stressors that affect soil organisms are usually related to changes in the type, intensity and duration of land use and management practices. These pressures can affect the habitats of soil biota, their species composition and their population abundance, which can, in turn, affect the ability of soil organisms to support vital soil functions required for optimal crop growth. Very little is known at regional scales about the population distribution of soil biota groups across Canada's various agroecosystems.

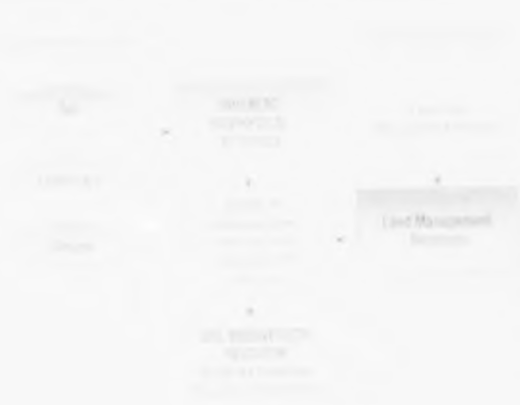
> *Living organisms in the soil provide essential benefits for the functioning of agroecosystems.*

THE INDICATOR

Soil biota population distribution patterns are controlled first and foremost by the environmental factors that characterize a given region (e.g. type of soil, landscape attributes, climatic conditions). The interactions among these environmental attributes determine the kind and the number of soil organisms that can exist in the soil habitat. From this perspective, the potential population distribution pattern can be defined as the Inherent Biophysical Response (IBR).

The Soil Biodiversity Indicator (see Figure 27-1) will reflect two aspects: first, a potential population abundance predicted for the different soil biota groups based on their Inherent Biophysical Response to the environment and second, the influence on this potential population abundance from anthropogenic impacts (Land Management Response). The anthropogenic impacts included in the Soil Biodiversity Indicator relate to the distribution patterns of land use (i.e. crop types) and agricultural management practices (i.e. tillage, residue) which affect the nature of the soil habitat to which the soil biota populations respond positively or negatively thereby influencing the extent of potential abundance as well as species composition.

Figure 27-1: Proposed framework concept for developing the Soil Biodiversity Indicator



CALCULATION METHOD

A preliminary framework is being developed for the Soil Biodiversity Indicator. The Inherent Biophysical Response (IBR) will be derived by using a model of population response as a function of soil attributes, combined with data on the response of soil biota groups to landscape attributes (e.g., elevation, slope) and climate variables. The response information will be derived from expert opinion combined with field evidence from experimental studies. The anthropogenic impacts of Land Management Response (LMR) will be determined at the Soil Landscapes of Canada (SLC) polygon level on the types of soil biota responses to the various kinds of land use (e.g. crop types) and management practices (e.g. tillage, soil amendments). The potential influence of these factors on soil biota populations will be assessed by drawing on field evidence, literature sources and expert opinion. The indicator will initially focus on the following soil biota groups: earthworms, soil arthropods and mycorrhizal fungi.

LIMITATIONS

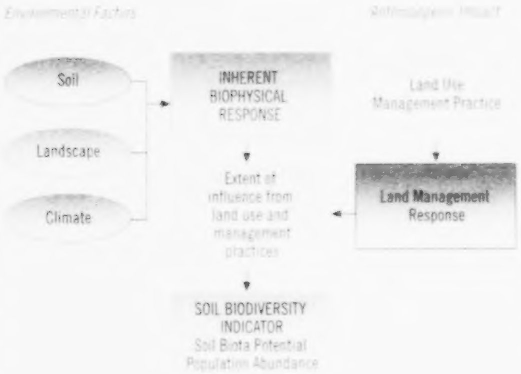
Because the exact response of soil biota to a particular specific soil agri-environmental condition is not known, there may be a high level of uncertainty in population responses based on available scientific information to soil attribute changes. Field verification will be necessary to validate the spatial and temporal of the response model from the standpoint of its ability to represent realistic population abundances of soil biota groups at the landscape scale. At present, Canada does not have a national database on soil biota distribution, and the predictive model approach using available data from experimental field studies is the most viable way to deduce trends in soil biota response (except at the field scale). In time, actual monitoring of soil biota populations across the landscape would not be feasible in Canada given the large spatial area involved.

Response data are required on the composition and ecological preferences of soil biota groups in the various regions of Canada and on the effects that changing patterns of land use and management practices have on these soil biota populations. Additional data are also needed on the individual environmental and anthropogenic stressors that affect specific soil biota groups. These data will be essential for refining the predictive models based on environmental attributes that are used to predict inherent potential population abundance and to identify the direction of response to anthropogenic impacts.

RESULTS

This indicator is currently under development and results are not yet available.

Figure 27-1: Proposed framework concept for developing the Soil Biodiversity Indicator


Environmental Factors
Anthropogenic Impact
Soil
Landscape
Climate
INHERENT BIOPHYSICAL RESPONSE
Land Use Management Practice
Extent of influence from land use and management practices
Land Management Response
SOIL BIODIVERSITY INDICATOR
Soil Biota Potential Population Abundance

■ CALCULATION METHOD

A preliminary framework is being developed for the Soil Biodiversity Indicator. The Inherent Biophysical Response (IBR) will be derived by using a model of population numbers as a function of soil attributes, combined with data on the response of soil biota groups to landscape attributes (i.e. elevation, slope) and climatic variables. The response information will be derived from expert opinion corroborated by field evidence from experimental studies. The anthropogenic impacts or Land Management Response (LMR) will be determined at the Soil Landscape of Canada (SLC) polygon level on the basis of soil biota responses to the various kinds of land use (e.g. crop type) and management practices (e.g. tillage, crop residues). The potential influence of these factors on soil biota populations will be assessed by drawing on field evidence, literature sources and expert opinion. The indicator will initially focus on the following soil biota groups: earthworms, soil arthropods and *mycorrhizal fungi*.

■ LIMITATIONS

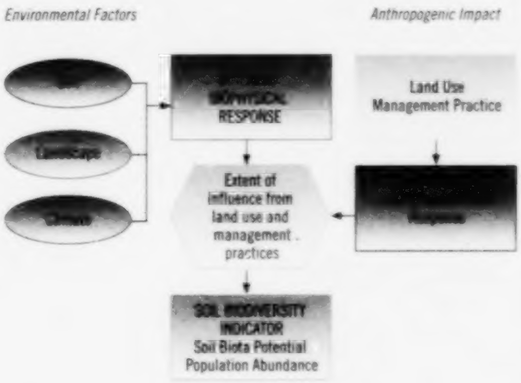
Because the Soil Biodiversity Indicator is a predictive model, it will represent a relative evaluation (from very low to very high) of the potential population abundance based on available scientific information as well as expert opinion. Field verification will be essential to confirm the quality and sensitivity of the response model from the standpoint of its ability to represent relative population abundances of soil biota groups at the landscape scale. At present, Canada does not have a comprehensive dataset on soil biota distribution. Still, the predictive model approach using scientific data from experimental field studies is the most viable way to obtain initial soil biota response maps at regional scales, because actual monitoring of soil biota populations across the landscape would not be feasible in Canada, given the huge spatial area involved.

Response data are required on the composition and ecological preferences of soil biota groups in key agroecosystems in Canada and on the effects that changing patterns of land use and management practices have on these soil biota populations. Additional data are also needed on the risk that environmental and anthropogenic stressors pose to specific soil biota groups. These data will be essential for refining the relational models based on environmental attributes that are used to predict inherent potential population abundance and to identify the direction of response to anthropogenic impacts.

■ RESULTS

This indicator is currently under development and results are not yet available.

Figure 27-1: Proposed framework concept for developing the Soil Biodiversity Indicator


Environmental Factors
Anthropogenic Impact
Landscape
Climate
BIOPHYSICAL RESPONSE
Land Use Management Practice
Response
Extent of influence from land use and management practices
SOIL BIODIVERSITY INDICATOR
Soil Biota Potential Population Abundance

■ CALCULATION METHOD

A preliminary framework is being developed for the Soil Biodiversity Indicator. The Inherent Biophysical Response (IBR) will be derived by using a model of population numbers as a function of soil attributes, combined with data on the response of soil biota groups to landscape attributes (i.e. elevation, slope) and climatic variables. The response information will be derived from expert opinion corroborated by field evidence from experimental studies. The anthropogenic impacts or Land Management Response (LMR) will be determined at the Soil Landscape of Canada (SLC) polygon level on the basis of soil biota responses to the various kinds of land use (e.g. crop type) and management practices (e.g. tillage, crop residues). The potential influence of these factors on soil biota populations will be assessed by drawing on field evidence, literature sources and expert opinion. The indicator will initially focus on the following soil biota groups: earthworms, soil arthropods and *mycorrhizal fungi*.

■ LIMITATIONS

Because the Soil Biodiversity Indicator is a predictive model, it will represent a relative evaluation (from very low to very high) of the potential population abundance based on available scientific information as well as expert opinion. Field verification will be essential to confirm the quality and sensitivity of the response model from the standpoint of its ability to represent relative population abundances of soil biota groups at the landscape scale. At present, Canada does not have a comprehensive dataset on soil biota distribution. Still, the predictive model approach using scientific data from experimental field studies is the most viable way to obtain initial soil biota response maps at regional scales, because actual monitoring of soil biota populations across the landscape would not be feasible in Canada, given the huge spatial area involved.

Response data are required on the composition and ecological preferences of soil biota groups in key agroecosystems in Canada and on the effects that changing patterns of land use and management practices have on these soil biota populations. Additional data are also needed on the risk that environmental and anthropogenic stressors pose to specific soil biota groups. These data will be essential for refining the relational models based on environmental attributes that are used to predict inherent potential population abundance and to identify the direction of response to anthropogenic impacts.

■ RESULTS

This indicator is currently under development and results are not yet available.

■ RESPONSE OPTIONS

According to literature sources and experimental studies, soil biota populations respond positively to soil conditions characterized by both minimal disturbance to soil habitat and a stable food supply (Fox 2003). Conservation tillage methods represent management practices that can help to meet these requirements, as they can maintain a reliable source of surface crop residues, reduce the effects of mechanical disturbance, compaction and soil erosion. Crop rotation, particularly if forages, legumes and cereal crops are included, provides a food source (carbon and nitrogen) at depth from penetrating root systems and improves soil structure, thereby enhancing soil habitat.

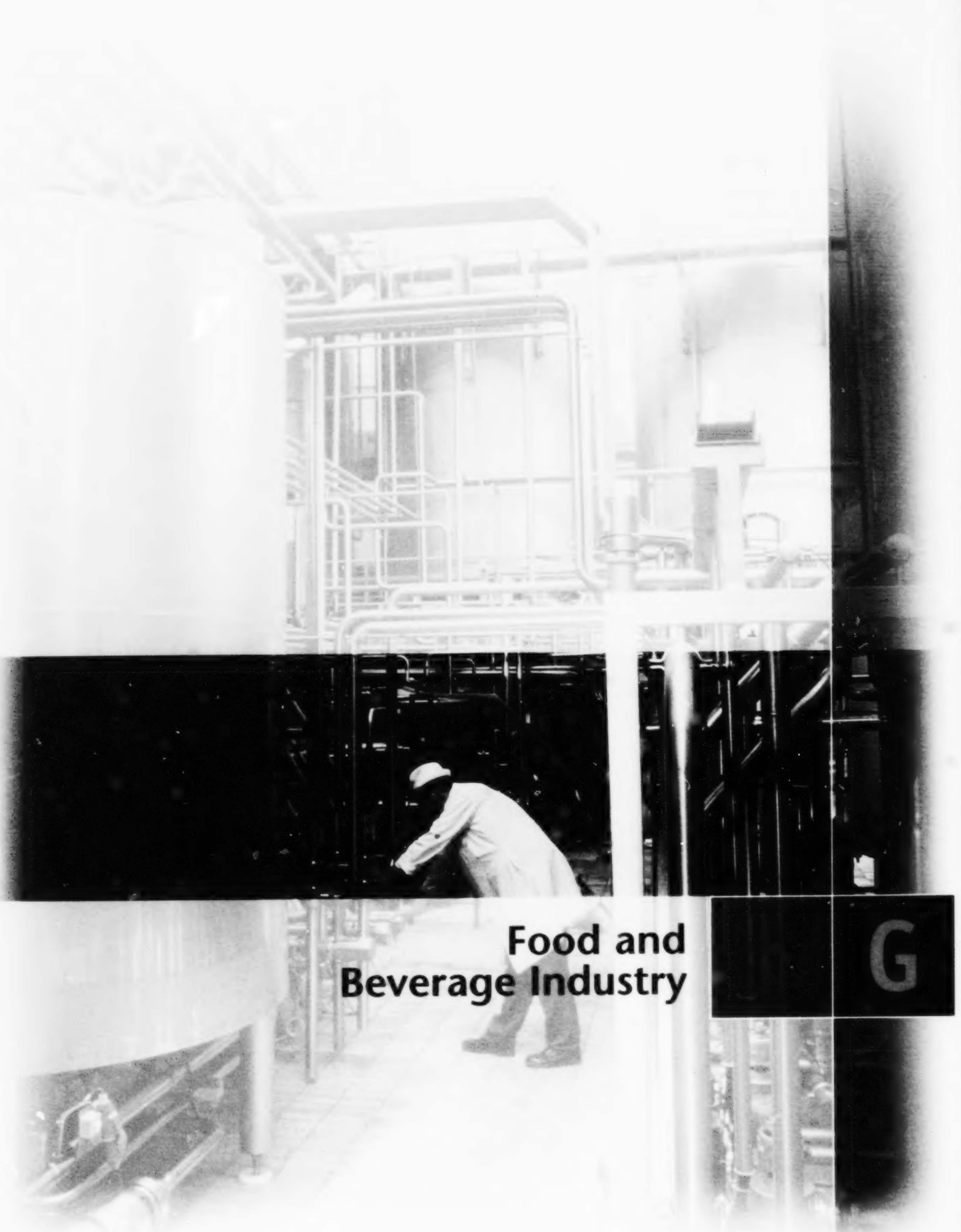
■ REFERENCES

Altieri, M.A., 1999. *The Ecological Role of Biodiversity in Agroecosystems*. Agriculture, Ecosystems & Environment. 74 (1-3): 19-31.

Brusaard, L., V.M. Behanpelletier, D.E. Bignell, D.E. Brown, W. Didden, P. Folgarait, C. Fragoso, D.W. Freckman, V.V.S.R. Gupta, T. Hattori, D.L. Hawksworth, C. Klopateck, P. Lavelle, D.W. Malloch, J. Rusek, B. Soderstrom, J.M. Tiedje, and R.A. Virginia, 1997. *Biodiversity and Ecosystem Functioning in Soil*, Ambio, 26 (8): pp. 563-570.

Fox, C.A. and K.B. MacDonald, 2003. *Challenges Related to Soil Biodiversity Research in Agroecosystems – Issues Within the Context of Scale of Observation*. Canadian Journal of Soil Science (special issue: Soil Biodiversity in Canadian Agroecosystems). 83: 231-244.

Fox, C. A., 2003. *Characterizing Soil Biota in Canadian Agroecosystems: State of Knowledge in Relation to Soil Organic Matter*. Canadian Journal of Soil Science (special issue: Soil Biodiversity in Canadian Agroecosystems). 83: 245-257.



Food and Beverage Industry

G

28. Energy Use and Greenhouse Gas Emission

AUTHORS:
M. Marcotte,
D. Maxime and
Y. Arcand

INDICATOR NAME:
(1) Energy Intensity Indicator
(2) Greenhouse Gas Intensity Indicator

STATUS:
Currently under development

■ SUMMARY

The food and beverage industry (FBI) requires energy for food processing, preservation, safety, storage and packaging. In most FBI subsectors, energy costs are typically small compared to raw material costs. However, with rising energy prices, there is a growing incentive for this industry to increase its energy use efficiency. Experts agree that there is real potential for gains in energy efficiency within this sector and that they could translate into a competitive economic advantage. In addition, since the various energy sources used in the FBI (natural gas, electricity, fuel oil, etc.) can affect the environment to varying degrees, energy use efficiency can be used to capture the environmental impacts associated with the sector's energy requirements. One environmental issue in particular that is closely linked to the industry's energy consumption is greenhouse gas (GHG) emissions. Through energy efficiency gains, the food and beverage industry has the potential to contribute to the national effort to meet Canada's reduction targets for GHG emissions.

Two eco-efficiency indicators are currently being developed to assess the following: (1) energy intensity in the FBI, or the consumption of energy per physical production unit (an aspect directly related to the energy use efficiency); and (2) GHG intensity, or the total quantity of GHG emissions generated per unit of energy consumed; this component will be used to assess the effect on GHG emissions of the various energy sources used in the industry.

■ THE ISSUE

The food and beverage industry requires energy for its operations. Most plants have a central fuel-burning boiler, and also consume electricity. This energy is distributed throughout the plant and is converted into thermal or mechanical energy for food processing operations, for food preservation and safety and for storage under controlled conditions as well as for packaging. Food preservation and safety are based on strict temperature control, whereas key processes involve heat and mass transfers. In hot processes (e.g. drying, cooking, frying, evaporation, pasteurization, sterilization), natural gas, petroleum-based products and electricity are generally used as energy sources, while cold processes (e.g. freezing, cooling, refrigeration) are almost entirely dependent on electricity. The energy demand composition has been relatively constant over the years in the Canadian food and beverage industry, with approximately 62% of energy derived from natural gas, 26% from electricity, 4% from fuel oil and 7% from other sources (e.g. propane, butane, coal) (Office of Energy Efficiency 2004).

For most FBI sectors, energy costs typically represent less than 10% of production costs, with the average proportion falling between 4% and 5% (see Table 28-1), whereas approximately 80% of direct manufacturing costs come from raw materials. This explains why there has been little incentive for the industry to pay close attention to its energy consumption. However, in recent years energy prices have shot up, rising faster than the consumer price index. This has pushed up processing costs and the cost of raw materials (primarily due to transportation), typically resulting in higher food and beverage prices. Since this economic impact is readily apparent to consumers, there is a direct incentive for the industry to enhance its energy efficiency.

An additional incentive comes from the fact that, as in most manufacturing sectors, the bulk (more than 80%) of greenhouse gas emissions in the FBI are directly tied to energy utilization (Competitive Analysis Centre Inc. 1999). Increasing energy efficiency in the FBI would therefore also reduce its greenhouse gas emissions. Over the last decade, the increase in

Table 28-1: Share of food and beverage manufacturing costs attributed to energy consumption

Food and beverage industry subsectors	Ratio of energy cost to cost of production
Corn milling	16%
Rendering and meat processing from carcasses	11%
Distilleries	10%
Rice milling and malt manufacturing	10%
Brewers	8%
Beverage manufacturing	7%
Sugar manufacturing	7%
Ice cream and frozen dessert manufacturing	6%
Other food manufacturing	5%
Animal food manufacturing	4%
Animal slaughtering	4%
Milling and oil manufacturing	4%
Fluid milk manufacturing	2%

Source: Navarri et al., 2001

greenhouse gas concentrations in the atmosphere has become a matter of global concern, and the Kyoto Protocol has been developed as a tool for slowing down the increase in atmospheric levels of GHGs. Under this Protocol, Canada has made an international commitment to reduce its GHG emissions to 6% below the 1990 level by 2012, and the pressure to implement policies that reduce GHG emissions is intensifying. While direct emissions of greenhouse gases from the food and beverage industry account for only 1.2% of overall GHG emissions in Canada (3.3% of the manufacturing sector's emissions) (Office of Energy Efficiency 2004), the FBI can play a role in meeting the reduction target for national emissions.

■ THE INDICATOR

Two subindicators have been developed in relation to these issues. First, the Energy Intensity Indicator (EII) is designed to assess the eco-efficiency of energy utilization in the food and beverage industry. Energy intensity in this context denotes the amount of energy required to produce one physical production unit (e.g. one tonne of meat or one hectolitre of beer). This indicator is similar to the one used by the Office of Energy Efficiency of Natural Resources Canada. The performance objective for the indicator would be a reduction in energy intensity.

While the EII provides an indication of the efforts devoted to increasing energy use efficiency, it does not evaluate the environmental effects, including GHG emissions, that may be generated depending on the nature and origin of the energy used. A second subindicator is therefore proposed—the Greenhouse Gas Intensity Indicator (GII)—for assessing the impact that various combinations of energy sources have on GHG production. For example, if more natural gas but less heavy fuel oil is used, the GII will diminish. In this context, "greenhouse gas intensity" denotes the total amount of GHG emissions generated per unit of energy consumed. The performance objective for this indicator would be a reduction in intensity, meaning that the FBI sector is using a "cleaner" blend of energy sources.

■ CALCULATION METHOD

The Energy Intensity Indicator will be an aggregate calculation using subsectoral data, reported provincially and nationally (see Chapter 2). It will be a ratio obtained by dividing energy consumption (EC) by production (physical production unit or PPU). Statistics Canada data on manufacturing shipments will be used to determine the production units. Two main data sources (Statistics Canada surveys) will be used in calculating the sum of the energy consumed by each of the FBI subsectors: the Annual Industrial Consumption of Energy Survey (ICES) (Office of Energy Efficiency 2004) and the Annual Survey of Manufactures (ASM), which tracks energy purchases as well as other industrial statistics. These surveys do not, however, evaluate the situation at the manufacturing stage or the operating unit level, which is where best operating practices are typically introduced. Voluntary plant audits and literature will therefore be used to obtain data at that level and refine the assessment. Conversion factors will be used to convert energy (e.g. fuel) quantities into standard energy units (terajoules) (Statistics Canada 2004).

The calculation for the GHG Intensity Indicator will be a ratio obtained by dividing total GHG emissions (reported in millions of tonnes (Mt) of CO_2 equivalent) by total energy consumption (same as EC above). GHG emissions will be derived mostly from the same energy use data as described above, but this time, the data will be broken down by component (electricity, natural gas, fuel oil, etc.) using published emission factors (Environment Canada 2004). Four major greenhouse gases are generated in the food and beverage industry: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and *refrigerants* (e.g. HFC-134a). The latest Global Warming Potential (GWP) values derived by the Intergovernmental Panel on Climate Change for these four gases (Houghton et al. 2001) will be used to allow comparison and combined reporting. GWP is the contribution that a gas makes to the greenhouse effect according to its capacity to absorb radiation and its residence time in the atmosphere. On-site GHG measurements are planned in order to validate assumptions and quantify the effect of best operating practices, thereby refining this assessment.

Increasing energy efficiency in the FBI would therefore also reduce its greenhouse gas emissions.

LIMITATIONS

The energy consumption values obtained from the Annual Industrial Consumption of Energy Survey are not broken down by region. This complicates the task of reporting results on a provincial basis. This limitation should be partly resolved through the concomitant use of results from the Annual Survey of Manufactures, which has a larger sample size.

The proposed approach based on using survey results can only account for GHG emissions associated with energy consumption. It will not take into account GHG emissions resulting from the breakdown of solid organic residues (estimated at 12% of total emissions). The calculated quantity will therefore underestimate the total GHG emissions. Furthermore, the GHG estimate is calculated using statistical conversion factors and so it may not always reflect the real situation in the industry, which will vary with the processes used. Some assumptions will have to be made regarding the completeness of the combustion of petroleum-derived products at the boiler. On-site measurements and analyses will have to be used for validation purposes.

RESULTS

Both subindicators are currently under development and results are not yet available.

RESPONSE OPTIONS

There is an abundance of literature indicating that there is a huge potential for reducing energy intensity in manufacturing sectors by making changes in manufacturing processes (e.g. going from batch manufacturing to continuous production) or by adopting best operating practices. Even in relatively standard processes such as those used in milk plants, studies have shown that energy consumption per litre of milk produced can double or triple depending on the practices applied, especially during high energy-consuming stages such as homogenization and pasteurization (Office of Energy Efficiency 2001). Some examples of best operating practices include more efficient boilers, motors and lighting systems, waste heat recycling and variable-speed motors. Plant audits can help identify the stages in which the greatest gains could be made. However, since most of these practices must be introduced in the manufacturing process, case-by-case studies are usually required. A few energy efficiency guides exist for some subsectors of the food and beverage industry, including the meat, poultry, beverage and dairy sectors (Natural Resources Canada and Agence de l'efficacité énergétique du Québec, 2002) and for breweries (Lom & Associates 1996), but guides like this have not been developed for all sectors yet.

The issues related to the effects of energy consumption on GHG emissions are well known. Best operating practices that can reduce GHG emissions are closely tied to those identified for achieving energy efficiency at the plant level. Reductions in GHG emissions can most likely be brought about by introducing basic energy conservation technologies, improving boiler control systems to ensure more complete combustion, using nitrogen instead of CO_2 in cooling tunnels and recovering methane, as well as capturing the CO_2 exhaust from boilers and converting it into non-volatile compounds. As with the energy intensity indicator, case-by-case studies will be required to identify the most beneficial best operating practices.

■ REFERENCES

Competitive Analysis Centre Inc. (CACI), 1999. *Food Processing Industry: Foundation Paper and Options Analysis*. Report of the Food Processing Industry Sub-Group, prepared for the Agriculture and Agri-Food Table on Climate Change, CACI, Ottawa (Ont.).

Environment Canada, 2004. *Canada's Greenhouse Gas Inventory 1990-2002*. Environment Canada, Greenhouse Gas Division, Ottawa (Ont.). http://www.ec.gc.ca/pdb/ghg/1990_02_report/toc_e.cfm

Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, K. Trenberth, and C.A. Johnson (eds), 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*. Published for the IPCC, Cambridge University Press, New York (NY). http://www.grida.no/climate/ipcc_tar/wg1/

Lom & Associates, 1998. *Energy Efficiency Opportunities in the Canadian Brewing Industry*. Brewers Association of Canada, Ottawa (Ont.). http://oee.rncan.gc.ca/infosource/pdfs/M27-01-945E.pdf

Natural Resources Canada, 2001. *Energy Performance Indicator Report: Fluid Milk Plants*. Natural Resources Canada, Office of Energy Efficiency, Ottawa (Ont.).

Natural Resources Canada, 2004. *Energy Use Data Handbook, 1990 and 1996 to 2002*, 3rd ed. Natural Resources Canada, Office of Energy Efficiency, Ottawa (Ont.). http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/home.cfm?text=N&printview=N

Natural Resources Canada and Agence de l'efficacité énergétique du Québec, 2002. *Guide sur les possibilités d'accroître l'efficacité énergétique dans l'industrie de la transformation des viandes et volailles, des boissons et de la transformation du lait*. Natural Resources Canada, CANMET Energy Technology Centre, Varennes (Quebec). http://www.aee.gouv.qc.ca/pdf/publications/guide_agroalimentaire.pdf

Navarri, P., A. Legault and S. Bédard, 2001. *Process Integration*. Presentation at the Seminar "Managing Waste and Wastewater in the Food Processing Industry", organized by Manitoba Hydro, November 21, 2001, in Winnipeg, Manitoba. Natural Resources Canada, CANMET Energy Technology Centre, Varennes (Quebec).

Statistics Canada, 2004. *Report On Energy Supply-Demand in Canada, 2003* (ongoing annual serial publication). Statistics Canada, Ottawa (Ont.).

29. Water Use and Effluent Generation

AUTHORS:

D. Maxime,
M. Marcotte
and Y. Arcand

INDICATOR NAME:

(1) Water Intake Intensity

(2) Wastewater Organic Discharge Intensity

STATUS:

Currently under development

■ SUMMARY

The food and beverage industry (FBI) draws significant quantities of water from the environment for its processing, product preparation and cleaning and sanitizing operations. This water use represents a substantial operating cost and puts pressure on a finite natural resource. Water quality is of paramount importance for meeting food hygiene and safety standards. A major portion of the water that is used (around 91%) is eventually returned to the natural environment, primarily through the public sewer system, as effluents carrying dissolved or suspended organic matter that may cause pollution. While these effluents are non-toxic, they must be treated in order to comply with local environmental standards, which can become quite onerous. Effluent quality has special significance for the industry, given the high water quality it requires. Incentives therefore exist for the FBI to mitigate the impacts of its production on water quality and availability.

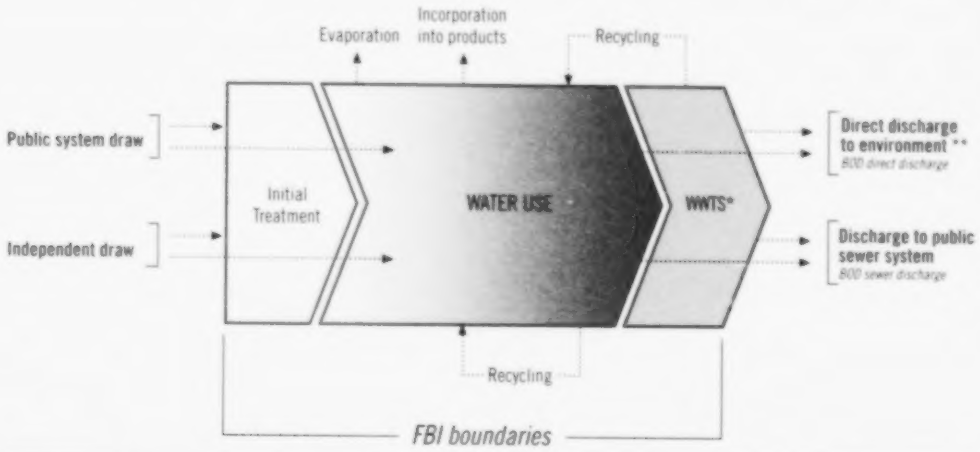
Two eco-efficiency indicators are currently being developed for use in assessing the following: (1) the water intake intensity of the FBI, or the amount of water drawn from the environment per physical production unit (an aspect directly related to water use efficiency); and (2) the wastewater organic discharge intensity, or the total quantity of organic matter contained in wastewater discharges per physical production unit. This will partly assess the extent of potential water contamination (or treatment costs) from FBI effluents.

■ THE ISSUE

Water holds an important place in manufacturing processes and in food preparation. The food and beverage industry (FBI) could simply not function without water supplies for its food processing operations: water is used as a manufacturing ingredient (preparation medium, packing medium, major ingredient in beverages); as a heat transfer medium (e.g. thawing or freezing, heating, pasteurization); as a solvent (e.g. extraction, pickling, brining); as a source of mechanical energy (e.g. transporting products); for washing, cleaning and sanitizing; for steam production in boilers; and for the disposal of certain wastes (Kirby et al. 2003). All of these requirements make the FBI a heavy water user, accounting for approximately 6% of total water use in the manufacturing sector (380.7 million cubic metres of water in Canada, in 1996) (Environment Canada 2002). A distinctive feature of the FBI's water use relates to the water quality that is needed. Depending on the intended use in the plant, and regardless of the source (drawn directly from wells, rivers, lakes or estuaries, or purchased from public utilities), the water may need to be treated before use, either for hygienic reasons (drinking water quality required for contact with food) or for technology reasons (purification required for supplying boilers).

Increased water use efficiency will translate into reduced pressure on this finite natural resource. Furthermore, most processes also generate effluents. Around 91% of the water used by processing plants is returned to the environment (primarily through public sewer systems) as effluents carrying dissolved or suspended organic matter that may be polluting. Any measure for optimizing water use can therefore help to reduce the level of pollution discharged to the environment. Because the food and beverage industry is so highly diversified, the effluents that are generated vary greatly in quantity and quality. However, there are some relatively common characteristics: high organic matter content (proteins, carbohydrates and fats), high chemical and *biochemical oxygen demand*, and, occasionally, a high nitrogen concentration. These effluents can either be chanelled into a public wastewater treatment system or treated on site in a dedicated facility prior to discharge directly

Figure 29-1: Primary water and wastewater flow in a food processing plant



* Wastewater treatment system (if applicable)
** Discharge subjected to regulatory acceptance

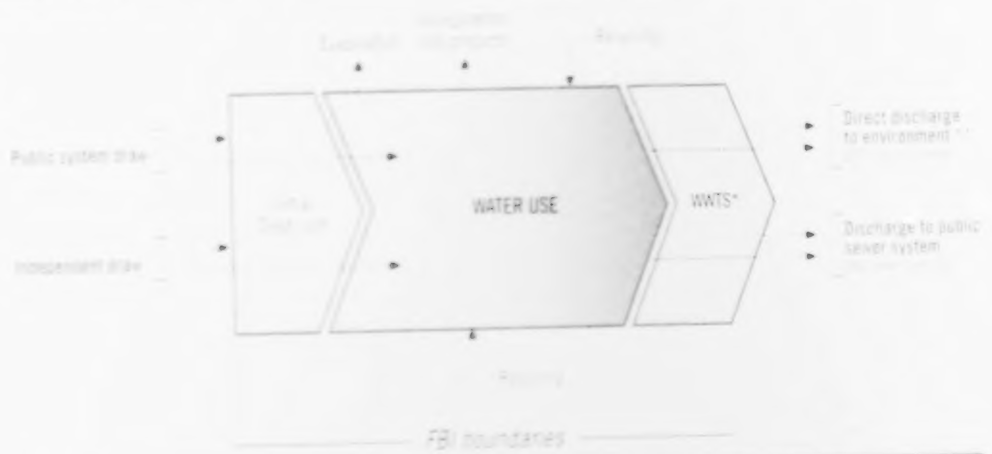
into the environment or into a sewer system (Figure 29-1). A portion of the wastewater can also be discharged untreated into the environment, provided it meets local discharge standards and internal reuse is not possible. Effluent quality is an issue that has considerable significance for the industry, given the high water quality it requires. In fact, depletion of high-quality water reserves in some parts of the country has already pushed up industrial water-supply costs and placed additional pressure on public water utilities to find new supply sources (Environment Canada 2004).

THE INDICATOR

Two indicators have been developed in relation to these issues. First, the Water Intake Intensity (WII) Indicator is designed to assess the eco-efficiency of water utilization in the food and beverage industry. Water intake intensity in this context denotes the volume of water withdrawn from the environment to produce one physical production unit (e.g. one tonne of food manufactured or one hectolitre of a beverage). This indicator will take into account all water drawn, whether directly from the environment or from the public water system, but will exclude recycled water (i.e. water reused in the plant at least once). An increase in the water recycling rate would translate into a decrease in water intake and hence an improvement in environmental performance.

While the WII provides an indication of the effort devoted to increasing water use efficiency, it does not reflect the water quality impacts that may occur depending on the amount and nature of the wastewater leaving FBI plants. A second indicator is therefore proposed—Wastewater Organic Discharge Intensity (WODI)—for assessing the total mass of organic matter that is discharged either directly into the environment or into the public sewer system in FBI effluent streams. In this case, "intensity" denotes the mass of organic discharge associated with one physical production unit. For both indicators, the performance objective would be a reduction in intensity, meaning that the food and beverage industry has increased its eco-efficiency by using less water or generating less organic pollution.

Figure 29-1: Primary water and wastewater flow in a food processing plant


Public system draw
Independent draw
WATER USE
WWTS*
Direct discharge to environment**
Discharge to public sewer system
FBI boundaries

into the environment or into a sewer system (Figure 29-1). A portion of the wastewater can also be discharged untreated into the environment, provided it meets local discharge standards and internal reuse is not possible. Effluent quality is an issue that has considerable significance for the industry, given the high water quality it requires. In fact, depletion of high-quality water reserves in some parts of the country has already pushed up industrial water-supply costs and placed additional pressure on public water utilities to find new supply sources (Environment Canada 2004).

■ THE INDICATOR

Two indicators have been developed in relation to these issues. First, the Water Intake Intensity (WII) indicator is designed to assess the eco-efficiency of water utilization in the food and beverage industry. Water intake intensity in this context denotes the volume of water withdrawn from the environment to produce one physical production unit (e.g. one tonne of food manufactured or one hectolitre of a beverage). This indicator will take into account all water drawn, whether directly from the environment or from the public water system, but will exclude recycled water (i.e. water reused in the plant at least once). An increase in the water recycling rate would translate into a decrease in water intake and hence an improvement in environmental performance.

While the WII provides an indication of the effort devoted to increasing water use efficiency, it does not reflect the water quality impacts that may occur depending on the amount and nature of the wastewater leaving FBI plants. A second indicator is therefore proposed—Wastewater Organic Discharge Intensity (WODI)—for assessing the total mass of organic matter that is discharged either directly into the environment or into the public sewer system in FBI effluent streams. In this case, "intensity" denotes the mass of organic discharge associated with one physical production unit. For both indicators, the performance objective would be a reduction in intensity, meaning that the food and beverage industry has increased its eco-efficiency by using less water or generating less organic pollution.

CALCULATION METHOD

The Water Intake Intensity (WII) Indicator will be calculated annually as the water intake volume divided by production. Water intake will be the sum of the volumes of water used (expressed in thousands of cubic metres), including all water drawn directly from the environment (groundwater, surface water and estuarine water) and from the public water system, but excluding water in raw materials. Rainwater and snow are also excluded, except where they are used in processing operations. The total volume of annual production will be expressed in units of mass for the production of solid foods and in units of volume for the production of liquids. Voluntary surveys will be used to collect data, since most plants have ready access to water use information (from purchase invoices and water intake statements) and production data. The indicator will be calculated for each plant surveyed and then aggregated provincially and nationally. The results will also be aggregated for the eight main FBI subsectors (see Chapter 2). Traditional water uses for an industrial plant (e.g. for staff needs and for building heating and air conditioning), which are usually included in statements and invoices, will be segregated in the survey. A number of detailed on-site evaluations will also be conducted to quantify the average requirements for various uses and allow for accurate validation of the survey approach.

Any measure for optimizing water use can therefore help to reduce the level of pollution discharged to the environment.

The Wastewater Organic Discharge Intensity (WODI) Indicator will be calculated as the total mass of organic discharge (in kg) divided by production. Total organic discharge will be calculated for each discharge that leaves a plant by taking the product of two data items: the organic load and the average flow. The organic load will be quantified using the total biological oxygen demand (BOD) of effluents leaving the plant. These quantities are usually known, as plants need this information in order to determine their water treatment requirements in accordance with the standards established by municipal authorities and/or the provincial department of the environment. Data will be collected through voluntary surveys. The indicator will be calculated for each plant surveyed and then aggregated provincially and nationally, as well as by FBI subsector.

LIMITATIONS

These two indicators have several limitations. They cannot cover every relevant aspect of water use and effluent generation. For example, wastewater reporting will be limited to organic discharge, although other parameters (e.g. nitrogen, phosphorus, pathogens, oils and fats, pH and *suspended particulates*) could have also been considered to cover a broader range of potential environmental impacts. However, indicator clarity would likely suffer if this broader approach were adopted. Another limitation relates to the fact that BOD does not necessarily measure the entire organic load contained in an effluent stream.

There are also some drawbacks to the chosen approach of presenting results in aggregate form, given the widely varying water use and effluent characteristics of processing plants, and the variations that can occur from one year to the next. Interpretation will be particularly difficult. For example, aggregation at the beverage subsector level may hide the fact that it takes two or three times more water, on average, to produce a litre of beer than a litre of carbonated beverage (Moletta 2002). Further limitations may be imposed by the need to protect the confidentiality of survey respondents, which could even preclude a regional or provincial breakdown for some subsectors.

RESULTS

Both indicators are currently under development and results are not yet available.

RESPONSE OPTIONS

Changes in practices and procedures and technological improvements (best operating practices) can have a positive effect on water intake intensity and organic discharge in effluents. For example, many industries have significantly reduced their water intake without necessarily reducing their water requirements, simply by implementing more efficient operating practices. No-cost or low-cost measures such as automatic supply shut-off, leak detection, *submetering* and water use monitoring are easy to implement and very beneficial. Water recycling opportunities may also be identified through process analyses or plant audits. They generally lead to concomitant energy savings (Wardrop Engineering 1999) since water is largely used as a heating or cooling agent. The approach needed to minimize water consumption successfully is also applicable to reducing contaminant levels in wastewater and may produce additional cost benefits, without compromising hygiene and quality standards. Pollution prevention practices are typically more complicated and expensive to implement because they involve acting on processes themselves. Reduced intensity (or increased efficiency) for both of these indicators could translate into substantial savings in terms of water use and wastewater treatment.

REFERENCES

Environment Canada, 2002. *Industrial Water Use, 1996*. Environment Canada, Sustainable Water Use Branch, Ottawa (Ont.). http://www.ec.gc.ca/water/en/info/pubs/sss/e_ind96.htm

Environment Canada, 2004., *Threats to Water Availability in Canada*. National Water Research Institute (NWRI), Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1. Environment Canada, NWRI, Burlington (Ont.). http://www.nwri.ca/threats2full/intro-e.html

Kirby, R.M., J. Bartram, and R. Carr, 2003. *Water in Food Production and Processing: Quantity and Quality Concerns*. Food Control. 14 (5): 283-299.

Moletta, R. (ed.), 2002. *Gestion des problèmes environnementaux dans les industries agroalimentaires*. (Collection Sciences & Techniques Agroalimentaires [STAA]). Tec & Doc, Paris (France).

Wardrop Engineering Inc., 1999. *Guide to Resource Conservation and Cost Savings Opportunities in the Ontario Meat and Poultry Sector*. Resource conservation sector guides series for the Ontario Ministry of the Environment. Wardrop, Toronto (Ont.).

30. Organic Solid Residues and Packaging Wastes

AUTHORS:
Y. Arcand,
M. Marcotte,
D. Maxime

INDICATOR NAME:

(1) Organic Residue Intensity (ORI) Indicator

(2) Required Packaging Intensity (RPI) Indicator

STATUS:

Currently under development

■ SUMMARY

The food and beverage industry (FBI) generates large amounts of solid residues, especially organic residues, as well as a large volume of packaging material. Organic residues are a direct output from raw material processing. Although they have a low toxic potential, their susceptibility to rotting (putrescibility) makes them a possible source of problems related to public health and the environment. Food and beverage packaging protects foods and beverages from spoilage, gives information about the products and facilitates transport. The task of disposing of packaging residues (after food consumption) falls to consumers in most cases. Solid residue disposal represents a direct cost for the FBI, as well as a potential lost opportunity when these materials are not recycled into valuable inputs. Eco-efficiency gains can be made when less material is used and less is returned to the environment. Whereas major recycling and reclamation efforts have been put in place at the processing and post-consumer stages, little is known about the overall performance of the Canadian food and beverage sector in this area.

Two eco-efficiency indicators are being developed to assess the following: (1) the organic residue intensity of the FBI, or the quantity of unsold organic material per physical unit of manufactured product, which gives an indication of the effectiveness of approaches used to minimize the quantity of organic residues generated; and (2) required packaging intensity, which will reflect the overall amount of packaging residues generated at the plant level and at the consumer level.

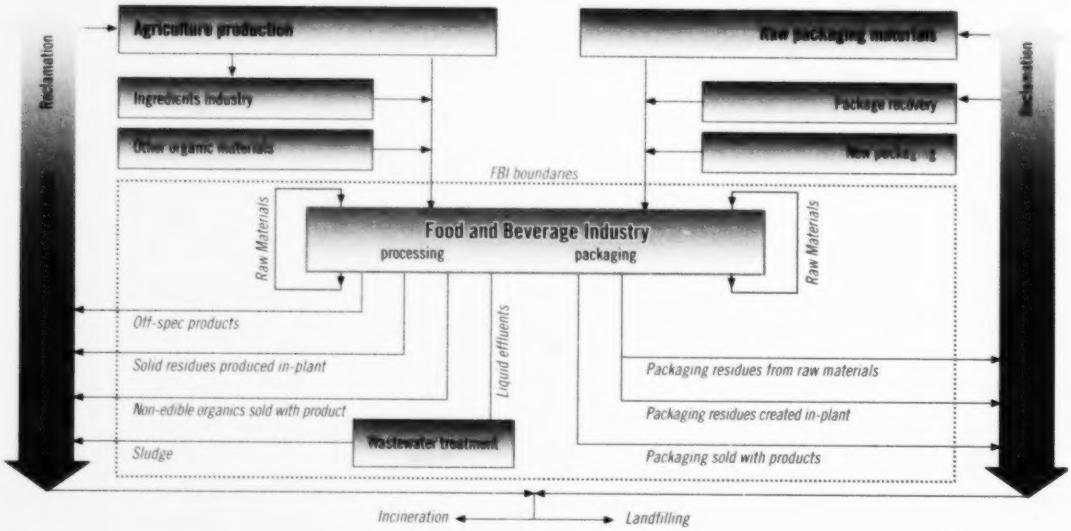
■ THE ISSUE

In 2002, more than 30.5 million tonnes of solid residues of all types were generated in Canada, approximately 971 kg per capita, of which 211 kg was recycled. Approximately 40% of the unrecycled portion came from residential collection, 49% from industrial, commercial and institutional collection and 11% from construction, renovation and demolition (Statistics Canada 2004). Although the food and beverage industry produces very few toxic or hazardous wastes (barring accidents), it generates a great deal of organic residues and is responsible for a large volume of food packaging waste.

Organic residual materials (ORM) are the direct outcome of raw material processing. For example, in the meat processing sector, the portion of processed products that is not intended for direct consumption often constitutes more than 40% of the mass of the original raw materials (Ockerman and Hansen 1998). The edible part of fruits and vegetables is only 10% to 50% of the raw materials (after sorting, peeling and eliminating "off-spec" products, i.e. those that do not meet quality standards, etc.). Some of these by-products are "recycled" as inputs for other products in the same or a different plant (e.g. rendering industry and production of animal feed) or as composting inputs or agricultural inputs (e.g. land application of organic wastewater sludge). Eco-efficiency gains can be made through source reduction or through the reuse, recycling or recovery of residues to provide valuable inputs. When this is done, less of the residues are returned to the environment, thus avoiding some problems that might otherwise arise because of their putrescible nature.

Packaging has three main functions: packages protect foods and beverages from spoilage; give information about products; and facilitate transport (for consumers as well as for upstream distribution). Packages are made from various materials (e.g. glass, metal, plastic, paper,

Figure 30-1: Flow of Organic and Food Packaging Residual Materials in the Food and Beverage Industry


Agriculture production
Raw packaging materials
Reclamation
Ingredients industry
Package recovery
Reclamation
Other organic materials
New packaging
FBI boundaries
Raw Materials
Food and Beverage Industry
processing
packaging
Raw Materials
Off-spec products
Liquid effluents
Solid residues produced in-plant
Packaging residues from raw materials
Non-edible organics sold with product
Packaging residues created in-plant
Wastewater treatment
Sludge
Packaging sold with products
Incineration
Landfilling

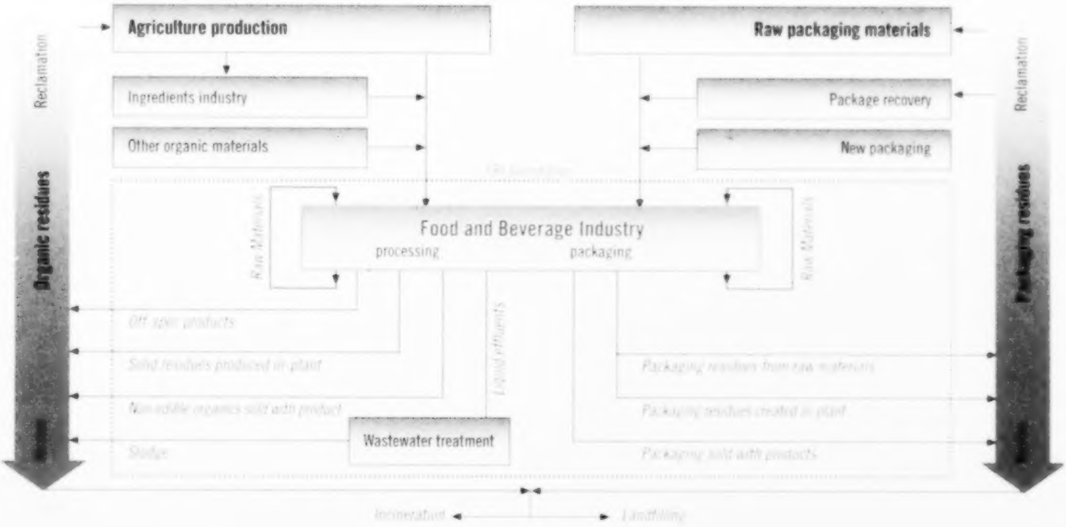
paperboard) that are combined in increasingly complex ways to create primary packaging (i.e. packaging that comes in direct contact with foods and beverages) that will meet very demanding technical specifications. In 1997, the food and beverage industry accounted for 56% of all packaging products used by manufacturing industries (Saint Pierre, 2000). Despite efforts to reduce the amount of material used in packaging, FBI packaging purchases are on the rise. One way that eco-efficiency gains can be made is by reducing the amount of material used in packaging. This can help to reduce the cost of raw packaging materials. It should be noted that food packaging is a market that generates revenues of over $20 billion in Canada (Richard 2003). Reducing the use of packaging materials can also alleviate some of the environmental pressures associated with managing packaging wastes.

Figure 30-1 illustrates the flow of organic residues and packaging residues in a typical FBI plant. For both, the management options range from complete disposal to recovery/reclamation. Whereas landfilling and incineration are disposal methods, reclamation methods involve reusing the materials within the system or recycling them. Two main streams can be tackled in striving for more effective management of solid organic residues and packaging: the industrial stream and the consumer stream. Each of these streams has different options for reclamation and disposal.

■ THE INDICATORS

Two indicators are being developed in relation to these issues. First, the Organic Residue Intensity (ORI) Indicator is designed to assess the eco-efficiency of organic residue management in food and beverage industry subsectors in Canada. More specifically, the indicator will be used to estimate the quantity of unsold organic material per physical unit of manufactured product and thus to evaluate the effectiveness of the approaches being used to minimize the quantity of organic residues generated. The indicator will consider all organic material entering a plant minus what is sold as a product or by-product. Any remaining material that must be disposed of by giving it away or paying for it to be taken away is considered a residue. The performance objective for this indicator would be a reduction in organic residue intensity.

Figure 30-1: Flow of Organic and Food Packaging Residual Materials in the Food and Beverage Industry


Agriculture production
Raw packaging materials
Reclamation
Ingredients industry
Package recovery
Other organic materials
New packaging
Organic residues
Packaging residues
Raw Materials
Food and Beverage Industry
processing
packaging
Raw Materials
Off spec products
Liquid effluents
Solid residues produced in plant
Packaging residues from raw materials
Non-edible organics sold with product
Packaging residues created in plant
Wastewater treatment
Sludge
Packaging sold with products
Incineration
Landfilling

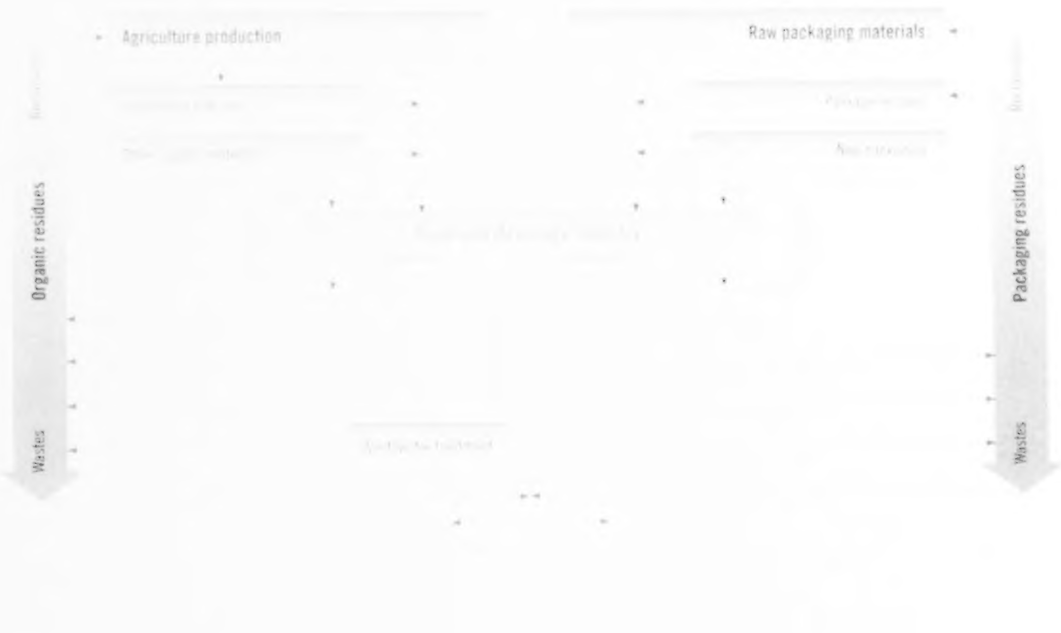
paperboard) that are combined in increasingly complex ways to create primary packaging (i.e. packaging that comes in direct contact with foods and beverages) that will meet very demanding technical specifications. In 1997, the food and beverage industry accounted for 56% of all packaging products used by manufacturing industries (Saint Pierre, 2000). Despite efforts to reduce the amount of material used in packaging, FBI packaging purchases are on the rise. One way that eco-efficiency gains can be made is by reducing the amount of material used in packaging. This can help to reduce the cost of raw packaging materials. It should be noted that food packaging is a market that generates revenues of over $20 billion in Canada (Richard 2003). Reducing the use of packaging materials can also alleviate some of the environmental pressures associated with managing packaging wastes.

Figure 30-1 illustrates the flow of organic residues and packaging residues in a typical FBI plant. For both, the management options range from complete disposal to recovery/reclamation. Whereas landfilling and incineration are disposal methods, reclamation methods involve reusing the materials within the system or recycling them. Two main streams can be tackled in striving for more effective management of solid organic residues and packaging: the industrial stream and the consumer stream. Each of these streams has different options for reclamation and disposal.

■ THE INDICATORS

Two indicators are being developed in relation to these issues. First, the Organic Residue Intensity (ORI) Indicator is designed to assess the eco-efficiency of organic residue management in food and beverage industry subsectors in Canada. More specifically, the indicator will be used to estimate the quantity of unsold organic material per physical unit of manufactured product and thus to evaluate the effectiveness of the approaches being used to minimize the quantity of organic residues generated. The indicator will consider all organic material entering a plant minus what is sold as a product or by-product. Any remaining material that must be disposed of by giving it away or paying for it to be taken away is considered a residue. The performance objective for this indicator would be a reduction in organic residue intensity.

Figure 30-1: Flow of Organic and Food Packaging Residual Materials in the Food and Beverage Industry


Agriculture production
Raw packaging materials
Organic residues
Wastes
Packaging residues
Wastes

[illegible]

[illegible]

[illegible]

THE INDICATORS

[illegible]

[illegible]

The second indicator that has been put forward—the Required Packaging Intensity (RPI) Indicator—will be used to estimate the quantity (mass) of packaging used per physical production unit manufactured. It will provide an indication of a given plant's efforts to reduce the quantity of packaging used annually (source reduction). It will take into account all packaging items associated with manufactured and marketed products in addition to residues generated at the plant (either received with raw materials or generated during processing). However, in the case of reused materials (e.g. wooden pallets or beer bottles), to prevent double-counting only replacements will be calculated. The performance objective for this indicator would be to reduce the total mass of all packaging material involved in the production and consumption of the product.

> *Although the food and beverage industry produces very few toxic or hazardous wastes it generates a great deal of organic residues and is responsible for a large volume of food packaging waste.*

■ CALCULATION METHOD

The Organic Residue Intensity (ORI) Indicator will be an aggregate calculation using subsectoral data reported provincially and nationally (see Chapter 2). The ORI is simply the total quantity (dry weight) of organic material from production residues, divided by production (physical production unit, or PPU). Economic data for manufacturing shipments from Statistics Canada will be used to determine these production units. The amount of organic residues that are produced by and that leave a given plant can be easily estimated from the difference between the total quantity of organic raw materials (entering the plant) used to produce one production unit and the quantity of organic material in that production unit (sold). A food company generally has these figures because it pays for raw materials and must keep records of product composition and the quantity of products sold. The sector-specific versions of Statistics Canada's Annual Survey of Manufactures provide physical and financial data on raw material purchases and the sale of finished products. They will be used for initial calculation of the indicators as described. A material balance will show the connection between raw materials processed into finished products and organic residual materials. In addition, a number of plants will be surveyed on a voluntary basis to obtain more detailed data, and on-site assessments will be conducted to validate the quality of the data obtained.

Similarly, the Required Packaging Intensity (RPI) Indicator will be an aggregate calculation using subsectoral data reported provincially and nationally. Calculating the RPI simply requires knowing the mass of the different packaging items that make up a transport unit (e.g. one pallet of product sold). Although these figures are not usually obtained directly, the total quantity purchased in one year divided by the number of pallets sold in the same period provides an excellent estimate. Estimating the reused portion (where applicable) may be somewhat more complex; however, an excellent approximation can be derived by estimating the purchases made to replace these items over a given period. In addition, packaging received with raw materials can be estimated by analysing incoming batches of raw materials. The indicator will encompass all items used for packaging, including primary packaging (comes in contact with food), secondary packaging (does not come in contact with food but end up in the hands of consumers) and packaging used for shipping (pallets, straps, film for packaging pallets, shipping crates, etc). Although these figures are not usually known directly, the total quantity purchased in one year divided by the number of pallets sold in the same period can be used as an estimate. Data on packaging purchases can be obtained (until 2004) from the Annual Survey of Manufactures and they will be used for initial calculation of the indicator.

LIMITATIONS

Complete and representative data on organic solid residues in the food and beverage industry are virtually non-existent (Richard 2003). Estimates will have to be derived and used in the indicator calculations, introducing error of unknown magnitude. Survey data will be used for both indicators, but they may not always reflect the true situation in the industry. It is not known at present whether the indicators will be sensitive to changes in operating practices that have environmental implications. On-site measurement and analysis will be a key component of the development and validation phases.

RESULTS

Both indicators are currently under development and results are not yet available.

RESPONSE OPTIONS

In general, applying the 4 R's of waste management, namely reduction, reuse, recycling and recovery (Richard 2003) should enhance the eco-efficiency of individual plants with respect to the generation of solid residues (organic and packaging). Various management methods and options are available that involve reusing or recycling organic by-products within the plant. Where this approach is applied outside the plant itself, the residue is transformed into a valuable product that can be used by another plant or industry. Creating composting products or agricultural inputs is another potential option for dealing with organic residues. The amount of packaging material that is sent to landfill sites can be reduced through packaging collection and/or recycling approaches (e.g. deposits on glass containers). Some efforts have already been made to improve the materials used. For example, plastic packages are 20% lighter today than they were 25 years ago (Deschênes 1997).

Reclamation technologies are not used much for packaging; however, considerable research has gone into developing biodegradable, compostable and even photodegradable packages. Life cycle assessment (LCA) is being used increasingly to compare the environmental pressures associated with packaging materials and to assist managers in evaluating the environmental pressures represented by the different packaging options available to them.

REFERENCES

Deschênes, L., 1997. *Emballage alimentaire: Quoi de neuf pour la conservation?* Le Monde Alimentaire. 1 (5): 24-28.

Ockerman, H.W. and C.L. Hansen, 2000. *Animal by-product processing and utilization*. Technomic, Lancaster (Pennsylvania).

Richard, F. (ed.), 2003. *Waste Management Guide for Small and Medium Enterprises – Canadian Version*. Éditions Ruffec and NI Environnement, Montreal (Quebec). http://www.qc.ec.gc.ca/dpe/Anglais/dpe_main_en.asp?innov_guide_mat_residuelles

Saint-Pierre, E., 2000. *Consumption of Packaging Products by Manufacturing Industries, Portrait and Trends*. Statistics Canada, Manufacturing, Construction and Energy Division, Ottawa (Ont.). http://www.statcan.ca/english/research/31F0027MIE/31F0027MIE2000001.htm

Statistics Canada, 2004. *Waste Management Industry Survey: Business and Government Sectors 2002*. Statistics Canada, Ottawa (Ont.). http://www.statcan.ca/english/freepub/16F0023XIE/16F0023XIE2002001.pdf

National and Regional Summary

H

31. National and Regional Summary

AUTHORS:
W. Eilers and
A. Lefebvre

SUMMARY

The agri-environmental indicators that are covered in this report are a practical means of assessing the sector's environmental sustainability by combining current scientific knowledge and understanding with available information on resource use and agricultural practices. These indicators are designed to be responsive to changes in key land use and farm management practices, making them effective tools for policy and program development.

Previous chapters of this report focus on individual agri-environmental indicators. In this chapter, we attempt to summarize the key findings from the soil, air, water and biodiversity indicators, and to highlight the main driving forces behind the results obtained. The 20-year trends summarized in this section refer to the period from 1981 to 2001. The trends are first presented for Canada as a whole and then for each province. Note that the national trends correspond to a national average; they are not necessarily uniform across the country since conditions, types and methods of production differ from one region to the other. It is interesting to note that, given the proportionally large share of agricultural production that comes from the three Prairie Provinces, the national trends are often driven by what occurs in the Prairies. Regional differences are highlighted in the provincial sections.

NATIONAL SUMMARY

Soil: All of the soil quality indicators showed considerable improvement (i.e. towards the desired state) nationally, between 1981 and 2001:

- the share of cropland in the high and very high soil cover classes went from 13% to 32%;
- the share of cropland in the very low risk class for water erosion went from 78% to 86%;
- the share of cultivated land (Prairies) in the very low risk class for wind erosion went from 72% to 86%;
- the share of cropland in the very low risk class for tillage erosion went from 38% to 50%;
- the share of cropland in the large soil organic carbon increase class went from 6% to 31%;
- the share of agricultural and adjacent non-agricultural land (Prairies) in the very low risk class for salinization went from 62% to 70%.

These positive changes came essentially as a result of a few key land management and land use trends. Two significant changes in land management occurred during the 20-year period: a 50% decrease in the area under summerfallow and a significant increase in the share of cropland under reduced tillage or no-till to the point where in 2001 up to 60% of cropland was under these practices. The soil conservation benefits resulting from these changes were further reinforced by a significant increase in the area of forage crops (31%), which are generally less intensive and require less tillage. This increase in forage crop area included the conversion of marginal cropland to forage production. The combined effect of these positive land management and land use trends outweighed the negative influence from a general shift to crops that provide lower cover and/or require more intensive management (e.g. canola, soybeans, pulse crops, potatoes), mostly at the expense of cereal crops. An additional soil quality indicator—risk of soil contamination by trace elements is currently under development.

Water: Only one water quality indicator is reported nationally, the Indicator of the Risk of Water Contamination by Nitrogen, along with its component farm management indicator—Residual Soil Nitrogen. These two indicators showed an overall increase in risk between 1981 and 2001:

- the share of cropland in the low and very low classes for residual soil nitrogen went from 74% to 28%;
- the share of farmland in the low and very low risk class for water contamination by nitrogen (N) went from 81% to 65%.

This overall increase in residual nitrogen (nitrogen remaining in the field after harvest) and in the risk of water contamination by nitrogen were also driven by land management and land use changes. With respect to land management, there was a significant national increase in fertilizer use (especially in the Prairies). For land use, there was an increase in the area of legume crops (increased atmospheric N fixation) and a general increase in livestock numbers (resulting in more manure N being applied to the land). This increase in available N was not matched by an equivalent increase in yields, thus causing a gradual and slow increase in risk between 1981 and 1996. The adverse climatic conditions that prevailed in 2001 affected yields and were responsible for an even more significant increase in risk between 1996 and 2001. Three other indicators are under development. The Indicator of the Risk of Water Contamination by Phosphorous is available only for Quebec (see below), but no results are available yet for the water quality indicators related to pesticides and pathogens.

Air: One indicator related to air quality is reported nationally—the Agricultural Greenhouse Gas Budget. This indicator showed an overall positive trend between 1981 and 2001:

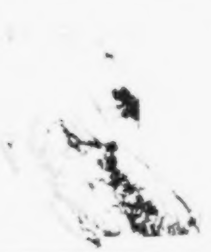
- the net GHG emissions (emissions minus sinks) decreased by 2.5 Mt CO_{2eq}, from 57.2 Mt CO_{2eq} to 54.7 Mt CO_{2eq}.

This overall decrease in the GHG budget for the agriculture sector mainly stems from changes in land use and management practices (reduced summerfallow, increased conservation tillage) that led to a significant increase in soil carbon sequestration (+12.5 Mt CO_{2eq}) (see soil indicators above). The increase in carbon sequestration in agricultural soils between 1981 and 2001 more than offset the appreciable increases in nitrous oxide (+6.7 Mt CO_{2eq}) and methane (+3.4 Mt CO_{2eq}) emissions, which are largely attributable to the substantial increase in the use of nitrogen fertilizer and the increase in beef cattle populations already mentioned above (water quality indicator). Two additional air quality indicators are currently being developed to address agricultural emissions of ammonia and particulate matter.

Biodiversity: For biodiversity, only one indicator is reported nationally—Wildlife Habitat on Farmland—which showed a slight deterioration between 1981 and 2001:

- 19% of the farmland showed either a moderate or large increase in wildlife habitat capacity, while 30% showed either a moderate or large decrease in wildlife habitat capacity.

This indicator was positively influenced by some of the land management trends discussed earlier (decrease in the species-impoverished summerfallow area) and by land use changes such as increases in the area of forage crops and the area of "all other land" (includes woodlots and wetlands), as well as by the conversion of about half a million hectares of marginal cropland on the Prairies to tame forages. However, these improvements did not completely offset the negative impact of the increase in the relative percentage of farmland used as cropland (from 47% to 53%) and the 3% decline in species-rich natural pastures. Three other biodiversity indicators are currently under development: risk of wildlife damage, soil biodiversity and risk from invasive alien species.



■ BRITISH COLUMBIA

Soil: All of the soil quality indicators showed considerable improvement (i.e. towards the desired state) in British Columbia between 1981 and 2001:

- the share of cropland in the high and very high soil cover classes went from 24% to 55%;
- the share of cropland in the very low risk class for water erosion went from 63% to 75%;
- the share of cropland (Peace River District) in the very low risk class for wind erosion went from 94% to 97%;
- the share of cropland in the low and very low risk class for tillage erosion went from 58% to 78%;
- the share of cropland with increasing soil organic carbon went from 32% to 38%.

These positive changes are in line with the national trends and arose mainly from broad land management and land use changes. Two significant changes in land management, occurred during the 20-year period of interest: a 42% decrease in area under summerfallow (from 9% to 6%), mainly in the Central Interior and Peace River regions, and an increase in the share of cropland under reduced tillage or no-till (from 17% to 36% of cropland). The positive effect on soil conservation was also influenced by the shift from crops requiring intensive tillage to crops requiring less tillage. As in the Prairies, there was a significant increase in forage production (from 53% to 67%). The combined impact of these positive land management and land use trends outweighed the negative influence from a 10% increase in cropland; a reduction in the area of higher-residue spring (-38%) and winter (-50%) wheat; and an expansion of the area under lower-residue crops (e.g. pulse crops, berries and grapes).

Water: The Indicator of Risk of Water Contamination by Nitrogen, along with its component indicator of Residual Soil Nitrogen, are applied in British Columbia. Similar to the national trend, these two indicators showed an overall increase in risk between 1981 and 2001:

- the share of cropland in the low and very low classes for residual soil nitrogen went from 75% to 58%;
- the share of farmland in the low and very low risk class for water contamination by N went from 62% to 51%.

This overall increase in residual nitrogen and in the risk of water contamination by nitrogen were driven by land management and land use changes. For land management, important factors include high nitrogen fertilizer sales and increases in available manure N (mostly from poultry), particularly in areas on Southeastern Vancouver Island and in the Lower Mainland. Here again, similar to the national trend, there was an increase in the legume crop area (increased atmospheric N fixation). This increase in available N was matched by a slight decrease in N outputs (yields).

Air: There were small fluctuations, but no overall change in net greenhouse gas emissions in British Columbia between 1981 and 2001:

- the net GHG emissions (emissions minus sinks) were constant at 2.6 Mt CO_{2eq} (approximately 5% of national agricultural emissions).

Nitrous oxide emissions were constant at 1 Mt CO_{2eq}, whereas methane emissions rose slightly (+0.1 Mt CO_{2eq}) mostly because of the increase in livestock populations. This increase was cancelled by an equivalent change in CO_2 (-0.1 Mt CO_{2eq}), resulting from a reduction in summerfallow and a slight increase in conservation tillage.

Biodiversity: Results for the Wildlife Habitat on Farmland Indicator showed an overall deterioration of the situation between 1981 and 2001:

- 12% of farmland showed either a moderate or large increase in wildlife habitat capacity, while 49% showed either a moderate or large decrease in wildlife habitat capacity.

While the decrease in the species-impoverished summerfallow area and the increase in the area of "all other land" (includes woodlots and wetlands), had a positive effect on this indicator, these improvements did not completely offset the negative impact of a 2% decline in species-rich natural pasture and a 3% decline in the relative percentage of tame pasture.

ALBERTA

Soil: In keeping with the national trend, all of the soil quality indicators showed considerable improvement between 1981 and 2001:

- the share of cropland in the high and very high soil cover classes went from 17% to 57%;
- the share of cropland in the very low risk class for water erosion went from 80% to 90%;
- the share of cropland in the very low risk class for wind erosion went from 86% to 94%;
- the share of cropland in the low and very low risk class for tillage erosion went from 66% to 87%;
- the share of cropland with increasing soil organic carbon went from 16% to 29%;
- the share of agricultural and adjacent land in the very low risk class for salinization went from 81% to 86%.

Changes in land management and land use were the most important driving forces for these improvements. The reduction of summerfallow area by 44% (nearly 1 million hectares) and the increase in the share of cropland under reduced tillage or no-till (from 27% of cropland in 1991 to 62% in 2001) were the key land management changes. The changes in land use contributing to this positive trend in soil conservation included a 49% increase in the area of forages and a 16% increase in pastures. The combined impact of these positive land management and land use trends outweighed the negative influence from a 15% increase in cropland, a reduction in the area of higher-residue cereal crops (-8%) and an expansion of the area under lower-residue crops such as pulses, oilseeds and potatoes.

Water: The Indicator of the Risk of Water Contamination by Nitrogen, along with its component indicator of Residual Soil Nitrogen, reflected the national trend, showing an overall increase in risk between 1981 and 2001:

- the share of cropland in the low and very low classes for residual soil nitrogen declined significantly from 93% to 56%;
- the share of farmland in the low and very low risk class for water contamination by N decreased from 97% to 87%.

Although Alberta had the lowest residual soil nitrogen (RSN) of all the Prairie Provinces, gradual increases in residual soil nitrogen and in the risk of water contamination by nitrogen were driven by significant increases in fertilizer use and manure production over the 20-year period under review. The increased area of N-fixing legume crops also contributed to this uptrend, albeit to a lesser extent. Fortunately increases in yields and N outputs compensated somewhat for the increased availability of nitrogen.

Air: Alberta was the province with the largest increase in net GHG emissions between 1981 and 2001:

- the net GHG emissions (emissions minus sinks) increased by 2.6 Mt CO_{2eq}, from 17.2 to 19.8 Mt CO_{2eq}, representing approximately 36% of national agricultural emissions.

Nitrous oxide emissions rose by 2.4 Mt CO_{2eq}, with this change being largely attributable to increased fertilizer use and manure nitrogen. An increase in methane emissions of 3.3 Mt CO_{2eq} resulted from the expansion of livestock populations during the 20-year period. These increases were offset by a reduction in CO_2 emissions of 3.1 Mt CO_{2eq}, which can be explained by the contraction of summerfallow area and the significant increase in conservation tillage.

Biodiversity: Similar to the national trend, Alberta posted slightly negative results overall for the Wildlife Habitat on Farmland Indicator between 1981 and 2001:

- 27% of farmland showed a decrease in wildlife habitat capacity, while 14% showed an increase.

Negative influences on wildlife habitat capacity in Alberta included an expansion of both total farmland and cropland as well as a small decrease in the area of tame pasture. Habitat capacity was positively influenced by a reduction in summerfallow area and an increase in the area of "all other land."

■ SASKATCHEWAN

Soil: Similar to the national trend, all of the soil quality indicators showed considerable improvement (i.e. towards the desired state) between 1981 and 2001:

- the share of cropland in the high and very high soil cover classes went from 0% to 10%, while the share in the very low class went from 45% to 3%;
- the share of cropland in the very low risk class for water erosion rose from 85% to 92%;
- the share of cropland in the very low risk class for wind erosion went from 62% to 81%;
- the share of cropland in the low and very low risk class for tillage erosion went from 32% to 72%;
- the share of cropland with increasing soil organic carbon went from 17% to 75%;
- the share of agricultural and adjacent land in the very low risk class for salinization went from 45% to 58%.

The general trend toward greater soil conservation in Saskatchewan was driven by changes in land management and land use. The decrease in summerfallow area (from 26% to 12% of farmland) and the declining use of conventional tillage for both summerfallow and seeding practices were the main land management changes contributing to enhanced soil conservation. Another factor behind this beneficial trend is the increased area devoted to forage and pasture (3%). The combined effect of these positive land management and land use trends outweighed the negative influence from the following: a 31% increase in cropland; reduced area of higher-residue cereal crops (-11%); and a 24% expansion in cropland producing lower-residue crops such as pulses and oilseeds.

Water: Similar to the national trend, the Residual Soil Nitrogen Indicator showed marked increases in residual N, while the Indicator of the Risk of Water Contamination by Nitrogen showed an overall increase in risk between 1981 and 2001, with most land still comprised in the lower risk classes:

- the share of cropland in the low and very low classes for residual soil nitrogen went from 89% to 18%;
- the share of farmland in the low and very low risk class for water contamination by N went from 95% to 79%.

This overall increase in residual nitrogen and in the risk of water contamination by nitrogen was driven by land management and land use changes. For land management, nitrogen fertilizer sales and available manure N (N inputs) increased throughout the period. Similar to the national trend, there was an increase in the area of legume crops (increased atmospheric N fixation). This uptrend in available N was not matched by an increase in N outputs. N outputs increased slightly each year until 2001, when climatic conditions may have depressed crop yields.

Air: Saskatchewan made the largest contribution to the national decrease in net GHG emissions between 1981 and 2001:

- the net GHG emissions (emissions minus sinks) decreased by 3.1 Mt CO_{2eq}, from 10.9 to 7.8 Mt CO_{2eq}, representing approximately 14% of national agricultural emissions.

Nitrous oxide emissions increased by 3.5 Mt CO_{2eq}, largely because producers increased their fertilizer use in order to better balance the removal/replacement ratio of nitrogen in prairie soils, a movement away from the traditional practice of underfertilization. A slight increase in methane emissions (0.8 Mt CO_{2eq}) resulted from the expansion of livestock populations over the 20-year period. Land management and land use changes that led to a large reduction in summerfallow area and an increase in the area under reduced tillage and no-till practices enabled the soils of Saskatchewan to become a carbon dioxide sink in 1996 and 2001. CO_2 emissions were 7.3 Mt CO_{2eq} lower in 2001, with 4.6 Mt CO_{2eq} of this amount being sequestered in the soil as organic carbon.

Biodiversity: Results for the Wildlife Habitat on Farmland Indicator indicate an overall improvement of the situation between 1981 and 2001:

- 35% of farmland showed either a moderate or large increase in wildlife habitat capacity, whereas 9% showed either a moderate or large decrease in wildlife habitat capacity.

The increase in wildlife habitat capacity in Saskatchewan can be explained by the significant decrease in summerfallow area from 26% to 12% of all farmland and a small increase in the "all other land" area. Negative factors affecting habitat capacity in Saskatchewan include an expansion of cropland (from 45% to 59% of all farmland) and a reduction in natural pasture (from 23% to 20% of all farmland).

MANITOBA

Soil: Similar to the national trend, all of the soil quality indicators showed considerable improvement (i.e. towards the desired state), between 1981 and 2001:

- the share of cropland in the moderate and high soil cover classes went from 38% to 85%, while the share in the low and very low soil cover classes went from 62% to 15%;
- the share of cropland in the very low risk class for water erosion went from 83% to 95%;
- the share of cropland in the very low risk class for wind erosion went from 75% to 82%;
- the share of cropland in the low and very low risk class for tillage erosion went from 76% to 91%;
- the share of cropland with increasing soil organic carbon went from 20% to 52%;
- the share of agricultural and adjacent land in the very low risk class for salinization went from 59% to 65%.

Changes in land management and land use were the main driving forces for these improvements. The 57% reduction of summerfallow area and the increase in the share of cropland under reduced tillage or no-till (from 34% of cropland in 1991 to 46% in 2001) were the primary land management changes. Land use changes that supported this positive soil conservation trend include a 41% increase in forage area. The combined effect of these positive land management and land use trends outweighed the negative influence from a 7% increase in cropland; a reduction in the area of higher-residue cereal crops (-16%); and an expansion of the area under lower-residue crops such as pulses, oilseeds and potatoes.

Water: Manitoba has the highest levels of residual nitrogen among the Prairie Provinces and the highest share of land in the high risk classes of the Indicator of the Risk of Water Contamination by Nitrogen. Both indicators showed an overall deterioration between 1981 and 2001:

- the share of cropland in the high and very high classes for residual soil nitrogen went from 85% to 89%;
- the share of farmland in the low and very low risk class for water contamination by N went from 12% to 4%.

The overall increase in residual nitrogen and in the risk of water contamination by nitrogen was driven by higher N inputs from fertilizers, increased available manure N and an increase in the area of legume crops (increased atmospheric N fixation). The increase in available N was offset somewhat by an increase in N outputs (yields) from 1981 to 1996; however, as in Saskatchewan, the level of N outputs decreased slightly in 2001, contributing to higher residual nitrogen and a higher risk of water contamination in that Census year.

Air: In contrast with the national trend, net GHG emissions in Manitoba increased between 1981 and 2001:

- the net GHG emissions (emissions minus sinks) increased by 1.1 Mt CO_{2eq}, from 6.3 to 7.4 Mt CO_{2eq}, representing approximately 13% of national agricultural emissions.

Nitrous oxide emissions increased by 2.0 Mt CO_{2eq}, largely because of increases in fertilizer use and manure nitrogen. A slight increase of 0.7 Mt CO_{2eq} in methane emissions resulted from the expansion of livestock populations during the 20-year period studied. Land management and land use changes resulting in a reduction in the summerfallow area and an increase in the area under reduced tillage and no-till practices enabled the soils of Manitoba to become a carbon dioxide sink in 2001. CO_2 emissions were 1.7 Mt CO_{2eq} lower in 2001, with 0.3 Mt CO_{2eq} of this amount being sequestered in the soil as organic carbon.

Biodiversity: Most of the farmland in Manitoba showed negligible to small changes for the Wildlife Habitat on Farmland Indicator, resulting in a slight overall decrease in capacity between 1981 and 2001:

- 7% of farmland showed either a moderate or large increase in wildlife habitat capacity, while 17% exhibited either a moderate or large decrease in wildlife habitat capacity.

While the large majority (75%) of Manitoba's farmland showed negligible or small changes in wildlife habitat capacity, thanks to the positive influence of some of the land management trends discussed earlier (decrease in the species-impoverished summerfallow area from 8% to 3%) and the increase in the area of "all other land" (from 5% to 9% of all farmland), these improvements did not completely offset the negative impact of the expansion of cropland from 58% to 62%.

■ ONTARIO

Soil: Soil quality indicators in Ontario showed results in keeping with the national situation, with an overall improvement between 1981 and 2001:

- the share of cropland in the moderate to very high soil cover classes went from 43% to 57%;
- the share of cropland in the very low risk class for water erosion went from 44% to 56%;
- the share of cropland in the low and very low risk class for tillage erosion went from 16% to 28%;
- the share of cropland with increasing soil organic carbon went from 17% to 30%.

These positive changes are similar to the national trends and came mostly as a result of similar land management and land use changes. The most significant change in land management over the 20-year period under review was the rising share of cropland under reduced tillage or no-till: by 2001, 48% of cropland was managed using these practices. It should be noted, however, that a significant share of the cropland in Ontario is still at elevated risk for degradation of soil quality. This is due to the increasingly high share of more intensively tilled crops grown in this province. For example, there has been a shift away from forages (-24%), grain corn (-8%) and spring cereals (-22%) to soybeans (+227%). Although the area of row crops has increased, the adoption of soil conservation tillage has tended to mitigate the overall risk of degradation of soil quality.

Water: Similar to the national trend, Ontario showed a general move away from the desired objective for both the Indicator of the Risk of Water Contamination by Nitrogen and the Residual Soil Nitrogen Indicator between 1981 and 1996, with a dramatic deterioration between 1996 and 2001:

- the share of cropland in the high and very high classes for residual soil nitrogen went from 20% to 81%;
- the share of farmland in the low and very low risk class for water contamination by N went from 60% to 9%.

This overall increase in residual nitrogen and in the risk of water contamination by nitrogen was driven by increased N inputs, which were linked mostly to higher biological fixation from increased soybean (20% each year) and alfalfa acreages as well as to increased livestock numbers (manure N from poultry and hog operations). The increase in available N was offset somewhat by higher N outputs (yields) from 1981 to 1996; however, N outputs decreased in 2001, contributing to higher residual nitrogen and a higher risk of water contamination in that Census year. The greater over-winter precipitation surplus in Ontario contributed to the estimated higher risk of residual soil nitrogen loss through leaching. In 2001, this situation was particularly indicated in southwestern Ontario regions such as the Lake Erie Lowlands region, where available manure-N was high.

Air: Ontario made the second largest contribution to the national decrease in net GHG emissions between 1981 and 2001:

- the net GHG emissions (emissions minus sinks) decreased by 2.1 Mt CO_{2eq}, from 11.5 to 9.4 Mt CO_{2eq}, representing approximately 17% of national agricultural emissions.

Although Ontario still accounts for nearly a fifth of net national agricultural GHG emissions, the trend over the 20-year period under review has been towards a reduction of total emissions. This downturn reflects a 17% decrease in nitrogen fertilizer sales in Ontario and a reduction in emissions from animals and from manure storage linked to a decrease in the total dairy and beef cattle population. These changes caused a 0.9 Mt CO_{2eq} decline in both methane and nitrous oxide emissions from 1981 to 2001, while the adoption of conservation tillage practices was largely responsible for a decline of 0.3 Mt CO_{2eq} in CO_2 emissions.

Biodiversity: Contributing to the national downward trend, Ontario posted an overall decrease in wildlife habitat capacity between 1981 and 2001:

- 94% of farmland showed either a moderate or large decrease in wildlife habitat capacity.

Land use changes are largely to blame for the decline in wildlife habitat capacity in Ontario. These changes included an increase in the percentage of farmland used for crops (from 60% to 67%) and a decrease in both natural pasture (from 13% to 9% of farmland) and tame pasture (from 11% to 6% of farmland).

■ QUEBEC

Soil: Contrary to the national trend, soil quality indicators in Quebec did not show significant improvements. Soil cover and soil organic carbon showed slightly negative trends. For the erosion indicators, while most of the land fell into the lower risk classes, there were only minor improvements between 1981 and 2001:

- the share of cropland in the high and very high soil cover classes went from 66% to 58%;
- the share of cropland in the very low risk class for water erosion went from 70% to 71%;
- the share of cropland in the low and very low risk class for tillage erosion went from 81% to 84%;
- the share of cropland with increasing soil organic carbon went from 18% to 17%.

Land use and management practices in Quebec underwent a significant change over this 20-year period. Changes that tended to increase the risk of soil degradation included decreases of 27% in forage area, 53% in pasture area and 10% in cereal grain areas, with concomitant increases of 3% in total cultivated land and 83% in row crops, mainly corn and soybean. Were it not for the moderate adoption of conservation tillage practices on 24% of cropland by 2001 and the fact that most of these agricultural activities take place on landscapes and soils that are not naturally prone to erosion, the risk of soil quality degradation might have increased significantly over this period.

Water: Similar to the national trend, Quebec showed an overall trend away from the desired objective for both the Indicator of the Risk of Water Contamination by Nitrogen and the Residual Soil Nitrogen Indicator between 1981 and 1996. On the other hand, the Indicator of the Risk of Water Contamination by Phosphorus showed some improvements during the 20-year period; however, the bulk of land still falls in the moderate and high risk classes:

- the share of cropland in the low and very low classes for residual soil nitrogen went from 68% to 33%;
- the share of farmland in the low and very low risk class for water contamination by N went from 80% to 63%;
- the share of farmland in the low and very low risk class for water contamination by P went from 18% to 29%.

The overall increase in residual nitrogen and in the risk of water contamination by nitrogen was driven by increased N inputs, associated mainly with a continued uptrend in fertilizer sales and manure increases resulting from higher poultry and hog numbers. Higher biological fixation from increased legume crop area also contributed to the N inputs. The increase in available N was offset somewhat by an increase in N outputs (yields) from 1981 to 1996; however, N outputs decreased in 2001, contributing to higher residual nitrogen and a higher risk of water contamination in that Census year. The greater over-winter precipitation surplus in Quebec contributed to losses of residual soil nitrogen through leaching. In 2001, this was particularly indicated in the Southern Laurentians, the Appalachians and the St. Lawrence Lowlands, where the high values were mainly caused by high livestock populations and available manure-N. The slight improvement in the risk of water contamination by phosphorus can be explained by the large increase in the area planted to grain corn, which is a high phosphorus-demanding crop, as well by the use of manure as a replacement for P from fertilizers. Changes in the livestock industry in Quebec have resulted in a 9% increase in the total amount of phosphorus available from manures in the last 10 years.

Air: Quebec followed the national trend with a small decrease in net GHG emissions between 1981 and 2001:

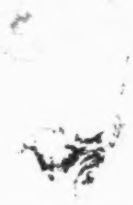
- the net GHG emissions (emissions minus sinks) decreased by 0.6 Mt CO_{2eq}, from 7.1 to 6.5 Mt CO_{2eq}, representing approximately 12% of national agricultural emissions.

Nitrous oxide emissions declined by 0.1 Mt CO_{2eq} during the 20-year period owing to reductions in emissions from animals and from manure storage associated with a decrease in the total dairy and beef cattle population. Methane emissions declined by 0.5 Mt CO_{2eq} because of a significant decrease in the total dairy cattle population. As mentioned in Chapter 21, since the methane emission factor for dairy cattle is almost twice that for beef cattle, the decrease in the dairy cattle population resulted in a net decrease in methane emissions. The low to moderate adoption of conservation tillage did not compensate for the decreased area of pasture and forages and the increased area under cultivation, hence a slight increase (0.1 Mt CO_{2eq}) occurred in emissions of CO_2.

Biodiversity: Similar to the situation in Ontario, and also contributing to the national downtrend, Quebec posted an overall decrease in wildlife habitat capacity between 1981 and 2001:

- 99% of farmland showed either a moderate or large decrease in wildlife habitat capacity.

As in Ontario, the decline in wildlife habitat capacity in Quebec is largely attributable to land use changes. These changes included an increase in the percentage of farmland used for crops (from 46% to 54%) and a decrease in both natural pasture (from 9% to 5% of farmland) and tame pasture (from 13% to 9% of farmland).



■ ATLANTIC PROVINCES

Soil: Soil quality indicators in the Atlantic Provinces showed mixed results, although there was an overall improvement between 1981 and 2001:

- the share of cropland in the moderate to very high soil cover classes went from a low of 81% (PEI) in 1981 to 100% in all four provinces in 2001;
- the share of cropland in the very low risk class for water erosion increased slightly in New Brunswick from 54% to 55% and in Nova Scotia from 61% to 65% but decreased in Prince Edward Island by 1% to 51%. (water erosion in Newfoundland and Labrador was not assessed);
- the share of cropland in the low and very low risk class for tillage erosion increased from 62% to 78% in New Brunswick, from 34% to 71% in Nova Scotia and from 30% to 62% in Newfoundland and Labrador but decreased from 41% to 19% in Prince Edward Island;
- the share of cropland with increasing soil organic carbon went from 43% to 53% in the four provinces combined.

Although land management and land use changes brought about a general improvement in the soil cover indicator, this was not reflected in the risk of water erosion. In all four provinces, the area of cropland increased and the amount of pasture decreased. The area of row crops increased in Nova Scotia and Prince Edward Island by 15% and 47% respectively. In Prince Edward Island, this situation is largely attributable to the increase in the area of potatoes, which are particularly prone to both water and tillage erosion, even when conservation tillage practices are used. Increases in conservation tillage practices in all four provinces and increases in the area of hay and fodder crops nonetheless played a beneficial role in mitigating erosion and maintaining soil organic carbon.

Water: Similar to the national trend, the Atlantic Provinces showed a general move away from the desired objective for both the Indicator of the Risk of Water Contamination by Nitrogen and the Residual Soil Nitrogen Indicator between 1981 and 1996, with a dramatic deterioration between 1996 and 2001:

- the share of cropland in the low and very low classes for residual soil nitrogen went from 42% to 16% in New Brunswick, from 74% to 7% in Nova Scotia, from 35% to 0% in Prince Edward Island and from 45% to 18% in Newfoundland and Labrador;
- the share of farmland in the low and very low risk class for water contamination by N went from 55% to 25% in New Brunswick, from 80% to 10% in Nova Scotia, from 59% to 0% in Prince Edward Island and from 49% to 30% in Newfoundland and Labrador.

The overall increase in residual nitrogen and in the risk of water contamination by nitrogen was driven by higher N inputs, which were mostly linked to increased livestock numbers (manure N from poultry and hog operations), and by higher biological fixation from the expanded area of alfalfa crops. The greater over-winter precipitation surplus in Atlantic Canada, coupled with the generally low available water holding capacity of the soils, contributes to losses of residual soil nitrogen through leaching.

Air: The Atlantic Provinces followed the national trend with a small decrease in net GHG emissions between 1981 and 2001:

- the net GHG emissions (emissions minus sinks) decreased by 0.4 Mt CO_{2eq}, from 1.6 Mt CO_{2eq} to 1.2 Mt CO_{2eq}, in the four provinces combined.

Net emissions of both methane and CO_2 declined over the 20-year period under study, while emissions of nitrous oxide remained virtually unchanged. Methane emissions declined by 0.1 Mt CO_{2eq} because of a significant decrease in dairy cattle and beef cattle populations. As mentioned in Chapter 21, since the methane emission factor for dairy cattle is almost twice that for beef cattle, the decrease in the dairy cattle population induced a net decrease in methane emissions. The low to moderate adoption of conservation tillage, combined with an increase in the total hay and fodder crop area (from 0.19 M ha in 1991 to 0.22 M ha in 2001), was sufficient to maintain emissions of CO_2 at the 1981 level despite the expansion (58 thousand ha) in the total area of cropland.

Biodiversity: Contributing to the national downward trend, the Atlantic Provinces posted an overall decrease in wildlife habitat capacity between 1981 and 2001:

- the share of farmland showing either a moderate or large decrease in wildlife habitat capacity was as follows: 87% in New Brunswick, 87% in Nova Scotia, 100% in Prince Edward Island and 66% in Newfoundland and Labrador.

The decline in wildlife habitat capacity in the Atlantic Provinces is largely attributable to land use changes. These changes included an increase in the percentage of farmland used for crops (New Brunswick: from 30% to 39%: Nova Scotia: from 24% to 32%; Prince Edward Island: from 56% to 67%; Newfoundland and Labrador: from 14% to 21%) and decreases in total pasture area of -48%, -40%, -50% and -55% for New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador, respectively.

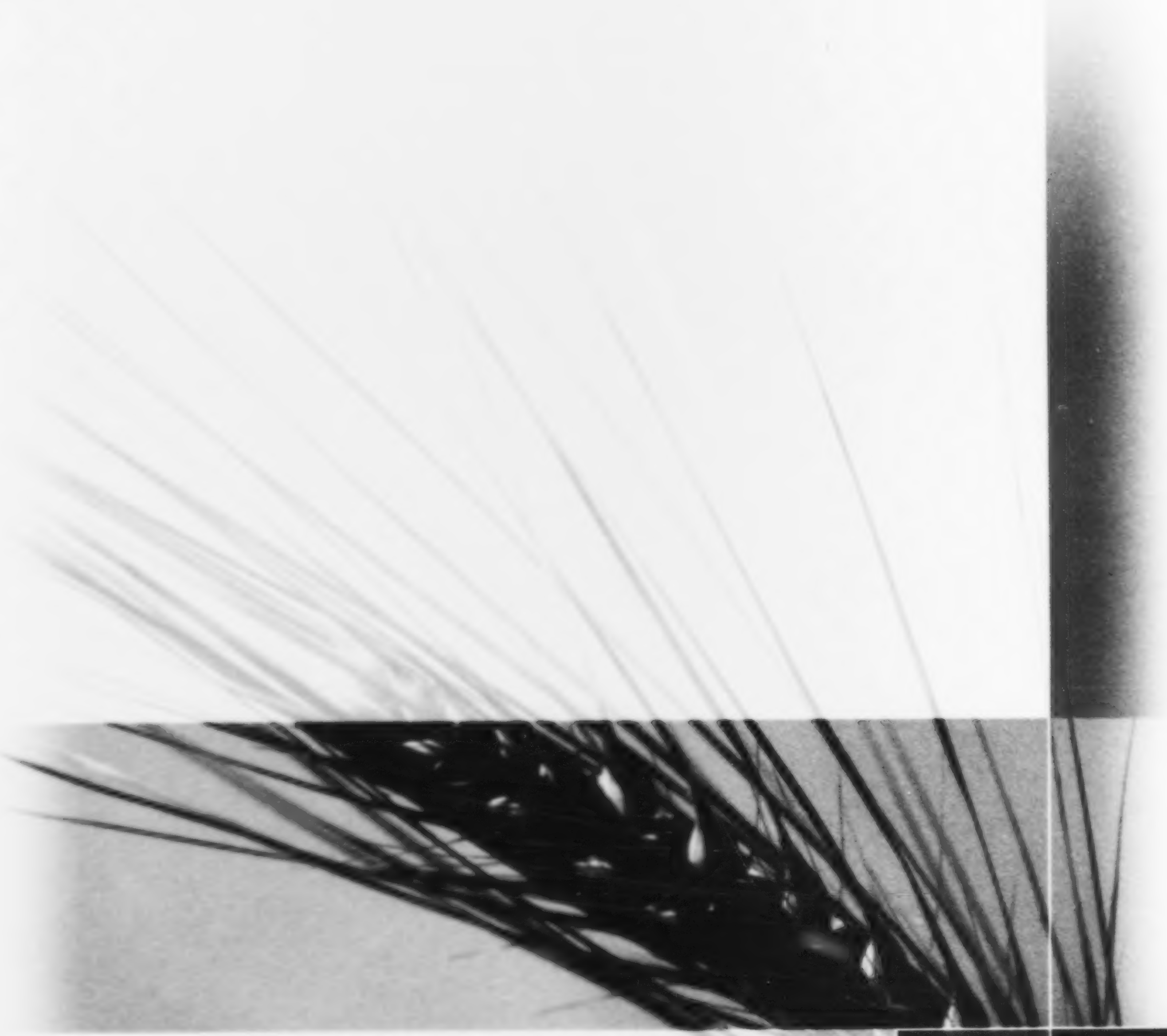
Conclusion

This national and regional analysis of environmental indicators reveals some consistent national trends, as well as considerable differences in various agri-environmental conditions across Canada. All the major agricultural region of Canada experienced some positive or negative trends as reflected by the indicator results. Overall, we found that changes in agricultural practices over the 20-year period under review have resulted in:

- a general improvement in soil management with numerous environmental benefits, including an overall reduction in soil erosion and net greenhouse gas emissions;
- increased environmental risks related to increases in residual nitrogen and in the risk of water contamination by nitrogen;
- either a steady state or a slight decrease in wildlife habitat capacity on farmland in all provinces except Saskatchewan.

The semi-arid prairie region is characterized by extensive crop production (cultivation of cereals, oilseeds and pasture) and both extensive and intensive livestock production. Together, the indicators suggest that considerable progress has been achieved towards environmental sustainability in this region. Reductions in the use of tillage, the area of summerfallow and the use of marginal lands have led to gains in soil conservation, soil quality and air quality, with the soils becoming a net sink for CO_2 (a greenhouse gas). In many areas, these types of land use change have also benefited wildlife. However, the expansion and intensification of cropping and livestock production have also increased emissions of the greenhouse gases nitrous oxide and methane, decreased wildlife habitat capacity in other areas, caused some soils to remain at risk of degradation and increased the chance of local water quality impacts because of increased fertilizer use and more-intensive animal production. Further intensification of crops and livestock production is likely to exacerbate the environmental risks unless appropriate actions are taken to manage them. Climatic, geographic and agricultural conditions are markedly different in the other (non-prairie) agricultural regions of Canada, where the more favourable climatic conditions permit more intensive forms of agriculture. These regions are characterized by the cultivation of higher-value crops (such as corn, potatoes, vegetables and soybeans) and by higher levels of inputs. Dairy, hog, poultry and beef operations are also prevalent. Land use changes in Central and Eastern Canada have included a reduction of total farmland area, but the area of cropped land has expanded in all the provinces. This more intensive form of agriculture in an environment with abundant water supplies may increase the potential environmental impacts associated with the agricultural sector.

Response options for environmental approaches to agriculture are provided in the different indicator chapters. All practices aimed at reducing soil disturbance have beneficial implications for soil quality, as well as for air quality given the potential for reducing GHG and particulate matter emissions. The beneficial implications for water quality consist of reduced surface run-off and enhanced erosion control, which can reduce the amount of nutrients, pathogens and pesticides entering the watershed system. Biodiversity benefits arise from the enhanced wildlife habitats and enhanced conditions for sustaining soil biodiversity, along with a less suitable environment for invasive species. Beneficial practices include the expanded use of conservation tillage methods (reduced tillage and no-till systems), the reduced use of summerfallow, crop residue management aimed at maintaining soil cover, forage use in crop rotations, strip cropping, companion or winter cover crops and efforts to target appropriate land use and management practices to the bio-physical properties and limitations of soil and landscape resources. A second means of enhancing environmental stewardship in agriculture consists in implementing beneficial management practices aimed at boosting efficiency in all sectors of agriculture, including the food and beverage processing industry. Some of the main practices for increasing input use efficiency at the farm level include developing and implementing an agri-environmental nutrient plan, regular soil testing and matching nutrient applications to crop requirements, growing winter cover crops where practical to enhance the uptake of nutrients remaining after the main crop is harvested and using other high nutrient-demanding crops in areas where nutrient surpluses are identified. Improving nutrient management in livestock diets is an effective mitigation strategy that can help minimize nutrient emissions to air, soil and water. Increasing the use of integrated pest management practices and new sprayer technologies is an effective way to reduce pesticide use. Increased water use efficiency contributes to maintaining or improving yields and also conserves water for other uses. Increased energy use efficiency will save money for producers and benefit the environment through reduced greenhouse gas emissions. In summary, continued improvement in farm management and land use practices are essential for maintaining and furthering the advances achieved in environmental stewardship within the agriculture sector.



Annexes

I

Glossary

Term	Definition
Agri-environmental indicator	A measure of a key environmental condition, risk or change resulting from agriculture; or a measure of management practices used by producers.
Agroecosystem	Species and ecosystems under agricultural management; an open, dynamic system connected to other ecosystems through the flow of energy and the transfer of material such as crops, pastures, livestock, other flora and fauna, air, soil and water.
All other land	*Census of Agriculture* category of agricultural land use denoting land occupied by farm buildings, barnyards, gardens, greenhouses, mushroom houses, idle land, woodlots, sugar bushes, tree windbreaks, bogs, marshes, sloughs, etc.
Ammonia	A compound of nitrogen and hydrogen (NH_3) formed naturally when bacteria decompose nitrogen-containing compounds, especially urea and uric acid, in manures. Emissions of ammonia can be a problem in enclosed livestock facilities and they can react with other compounds to produce fine particulate matter in the ambient air. Ammonia is a component of some fertilizers and an important plant nutrient. It can also be used as a refrigerant in the Food and Beverage Industry.
Anaerobic	Characterized by the absence of oxygen.
Anthropogenic	Involving the impact of humans on nature; induced or altered by the presence or activities of humans.
Arable land	Land that can be cultivated.
Atmospheric wash-out	The process by which a chemical that is dissolved in water in the atmosphere reaches land or a water body through precipitation.
Bare soil	Soil not covered by a crop canopy or crop residue and exposed to the elements.
Beneficial management practices	Methods, measures or practices designed to minimize or prevent environmental risks and negative effects on the environment, including pollution.
Bioavailability	The proportion of a nutrient or a toxic substance that can be taken up by an organism in a biologically effective form.
Biochemical oxygen demand	A measure of the amount of oxygen consumed in water due to natural biological processes that break down organic matter, such as those that take place when food residues are put in the water. Excess of anthropogenic organic wastes in water can deplete dissolved oxygen (DO), endangering aquatic life.
Biodiversity	The variety of life forms on earth and the natural processes that link and maintain them. Biodiversity has three components: ecosystem diversity, species diversity and genetic diversity. Also called biological diversity.
Biofuel	A gaseous, liquid or solid fuel derived from a biological source, such as methane, ethanol, rapeseed oil or fish liver oil.
Biomass	Total mass of a species or group of species per unit area; or the total mass of all the species in a community.
Biopesticide	A pest control agent that is biological in origin (i.e. viruses, bacteria, natural plant compounds) as opposed to synthetic chemicals.
Bioplastics	Biodegradable plastics made from natural resources such as starch, cellulose and proteins.
Bioremediation	Process of restoring a natural area through the use of living organisms (e.g. plants or bacteria).
Biosolid	The soil-like residues of materials that are removed from sewage during treatment processes. During treatment, bacteria and other organisms break sewage down into simpler forms of organic matter which, combined with bacterial cell masses, settles to form biosolids.
Biota	All the living organisms of a particular place or time.
Biotechnology	In agriculture, refers to the science and methods of genetic engineering used to produce new varieties of crops or livestock with superior traits.
Black soil	Grassland soil type occurring on the Canadian Prairies, characterized by a very dark surface, a brownish B horizon and usually a calcareous C horizon.
Bovine spongiform encephalopathy	Commonly known as "mad cow disease," bovine spongiform encephalopathy (BSE) is a progressive, incurable disease that affects the central nervous system of cattle.
Brown soil	Grassland soil type occurring on the semi-arid Canadian Prairies, characterized by a brown surface, a lighter brown B horizon and usually a calcareous C horizon.
Carbon (C)	Element present in all materials of biological origin.
Carbon dioxide (CO_2)	Major greenhouse gas produced through the decomposition of organic matter in soils under oxidizing conditions; also produced by the burning of fossil fuels.

Term	Definition
Carbon dioxide equivalent (CO_{2eq})	Expression of the effectiveness of a gas to produce a greenhouse effect in the atmosphere in terms that compare it with that of carbon dioxide.
Carbon sequestration	Biochemical process by which carbon is transferred from the atmosphere by living organisms, including plants and micro-organisms to another carbon pool such as soils or forests with the potential to reduce atmospheric carbon dioxide levels.
Census of Agriculture	National agricultural Census undertaken every five years to compile information on farm structure and economics, crops and land use as well as livestock.
Chem-fallow	Control of weeds on summerfallow land using herbicides instead of tillage. Also called chemical fallow.
Clay soil	Soil material that contains 40% or more clay, less than 45% sand and less than 40% silt.
Composting	The controlled biological decomposition of a mixture of organic residues often comprising soil, which is kept in piles and periodically moistened.
Conservation tillage	Any tillage sequence designed to minimize or reduce the loss of soil and water; operationally, a tillage or tillage and planting system that leaves 30% or more crop residue cover on the soil surface.
Continuous cropping	Practice of growing crops every growing season with no fallow years or growing the same crop on the same land year after year.
Contour cultivation	Cultivation on the contour of the land, rather than up and down slope, to reduce soil erosion, protect soil fertility and use water more efficiently.
Conventional tillage	Primary and secondary tillage operations normally performed in preparing a seedbed, usually resulting in less than 30% crop residue cover on the soil surface.
Cover crop	Secondary crop grown after a primary crop or between rows of the primary crop to provide a protective soil cover that will minimize soil erosion and leaching of nutrients.
Crop residue	Plant material remaining after harvesting, including leaves, stalks and roots.
Crop rotation	Agricultural practice that consists of growing two or more crops or crop types on the same land in consecutive years in a repetitive pattern. Rotation is usually done to increase soil fertility, reduce pest populations and sustain agricultural production in future years.
Cropland	Census of Agriculture category of agricultural land use denoting the total area on which field crops, fruits, vegetables, nursery crops and sod are grown.
Cultivated land	Land tilled and used to grow crops, includes land left fallow.
Dark brown soil	Grassland soil type occurring on the Canadian Prairies, characterized by a dark brown surface, a lighter brownish B horizon and usually a calcareous C horizon.
Decomposition	Breakdown of complex organic matter into simpler materials by micro-organisms.
Degree-day	Difference between the daily mean temperature and a reference temperature—defined for a crop or an insect pest—accumulated over its development. The degree-day is a useful indirect measure of the heat available for growth and development.
Denitrification	A chemical process in which nitrates in the soil are reduced to molecular nitrogen, which is released to the atmosphere.
Depredation	Crop or livestock losses caused by the predatory actions of wildlife.
Dissolved oxygen	Refers to oxygen freely available in water, which is vital to fish and other aquatic life and necessary for the prevention of odours in water.
Drainage	Procedure carried out to improve the productivity of agricultural land by enhancing the removal of excess water from the soil by means such as ditches, drainage wells and subsurface drainage tiles.
Dryland	Type of farming that depends exclusively on natural precipitation and soil moisture to supply water to crops (i.e. non-irrigated). Sometimes called "rainfed".
Ecodistrict	A subdivision of an *ecoregion* characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies and fauna. See ecoregion.
Eco-efficiency	A process designed to produce more or higher-value products or services while using fewer inputs such as material and energy, in turn minimizing environmental impacts.
Ecoregion	Mapping unit in Canada's ecological classification system. A subdivision of a larger ecological classification unit characterized by distinctive regional ecological factors, including climate, physiography, vegetation, soil, water and fauna.
Ecosystem	A unit of land or water comprising populations of organisms considered together with their physical environment and the processes linking them.

Term	Definition
Ecozone	Largest mapping unit in Canada's ecological classification system. An ecozone is an area of the earth's surface representative of large and very generalized ecological units characterized by interactive and adjusting abiotic and biotic factors. Agriculture is carried out in seven of Canada's 15 ecozones.
Effluent	Any liquid or gaseous waste material that is discharged from a system into the environment or into a collecting system (e.g. sewage).
Emission factor	An estimate or statistical average of the rate at which a contaminant is released to the atmosphere through some activity (e.g. farming, burning of fuel), divided by the level of that activity. Given an emission factor and a known activity level, a simple multiplication yields an estimate of the actual emission.
Energy input	Non-renewable energy (i.e. not including sunlight) that is used in agricultural systems, for example, to power vehicles and farm machinery, to manufacture equipment and chemicals (e.g. fertilizer, pesticides) and to manage a farmhouse.
Energy output	Energy embodied in the products of agriculture that are used or consumed by humans.
Enteric bacteria	Group of bacteria that live in the intestinal tracts of humans and other animals.
Environmental farm management	Managing a farm with a view to environmental sustainability. See beneficial management practices.
Environmental farm plan	Plan outlining the environmental concerns related to a given farm and the steps required to address them. This type of plan is prepared and implemented by farmers on a voluntary basis.
Environmental sustainability	Management approach that seeks to protect natural resources and ensure they are available for future generations. This approach stresses the importance of ecological integrity in maintaining earth's life-support systems.
Erodibility	The susceptibility of a soil to erosion.
Erosivity	Measure of the predictable capacity of water, wind, tillage or other agents to cause erosion.
Ethanol	Liquid that is produced chemically from ethylene or biologically from the fermentation of various sugars found in agricultural crops and cellulose residues from crops or wood. Depending on how it is produced, it can be used as a substitute for fossil fuels and thus reduce greenhouse gas emissions. Also known as ethyl alcohol or grain alcohol.
Eutrophication	The process by which a body of water acquires a high concentration of plant nutrients, especially nitrates and phosphates. This nutrient enrichment promotes the excessive growth of algae, which can lead to depletion of dissolved oxygen and kill aquatic organisms such as fish.
Evapotranspiration	Movement of water into the atmosphere by evaporation from the soil and transpiration from plants.
Fermentation	A biochemical reaction that breaks down complex organic substances, especially carbohydrates, into simpler materials (ethanol, carbon dioxide, and water), usually occurring in the absence of oxygen.
Fertilizer	Any organic or inorganic material, either natural or synthetic, used to supply elements (such as nitrogen, phosphorus and potassium) essential for plant growth.
Forage	Grass or legume crop grown to provide livestock feed; may be stored dry as hay or under moist conditions as silage, plowed into the soil as green manure, or grazed.
Fossil fuel	Carbon-based remains of organic matter that has been geologically transformed into coal, oil or natural gas. Combustion of these substances releases large amounts of energy. Fossil fuels are used to supply a large proportion of human energy needs.
Fumigant	Any pest control substance that is a vapour or gas, or forms a vapour or gas on application.
Global Warming Potential (GWP)	Measure of the ability of a greenhouse gas to trap radiation and thus contribute to global warming (rise in global temperatures).
Grassed waterways	Natural or constructed channel, usually broad and shallow, covered with erosion-resistant grasses, used to convey surface water from or across cropland along natural depressions.
Greenhouse gas	Greenhouse gases absorb and trap heat in the atmosphere and cause a warming effect on earth. Some occur naturally in the atmosphere, while others result from human activities. Greenhouse gases include carbon dioxide, water vapour, methane, nitrous oxide, ozone, chlorofluorocarbons, hydrofluorocarbons and perfluorocarbons.
Ground water	Portion of water below the soil surface which has the water table as its upper boundary. This water supplies wells and springs.
Habitat quality	Fitness of a habitat to provide for the needs of a species.
Homogenization	The process of physically reducing the particle size of fat in milk, thus enabling an even distribution of fat throughout the milk.
Humid region	Pertaining to a climate in which the lower limit of annual precipitation is 50 cm in cool regions and the upper limit is 150 cm in hot regions.

Term	Definition
Hybridization	Breeding of individuals from genetically different strains, populations or species.
Indigenous biodiversity	The variety of life forms that are native to a particular area and the natural processes that link and maintain them.
Inorganic	Pertaining to a compound that is not organic, usually of mineral origin.
Integrated pest management	Decision-making process that uses all the necessary techniques to suppress pests effectively, economically and in an environmentally sound manner. Integrated pest management, or IPM, is an ecologically based strategy that relies on natural mortality factors, such as natural enemies, weather and crop management, and applies control measures that disrupt these factors as little as possible.
Interseeding	Seeding a secondary crop into a primary crop to provide enhanced soil cover, nutrient control, pest control or other production benefits.
Invasive alien species	Alien (non-native) species (plant, animal or micro-organism) whose introduction causes or is likely to cause economic or environmental harm or harm to human health.
Invasiveness	Ability of a plant to spread beyond its introduction site and become established in new locations, where it may adversely affect other organisms.
Irrigation	Artificial watering of crops by various methods.
Leaching	Process by which soluble substances are dissolved and transported through the soil by percolating water.
Life cycle assessment	Technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by compiling an inventory of relevant energy and material inputs and environmental releases; evaluating the potential environmental impacts associated with all identified inputs and releases; and interpreting the results to aid in making a more informed decision.
Loamy sand soil	Soil material containing a mixture of sand, clay and silt, in which sand particles are predominant, followed by clay particles. For example, a soil sample consisting of 90% sand and 10% clay falls into the loamy sand soil category. Note that this soil contains less clay than a sandy loam soil.
Methane (CH_4)	Gas produced through anaerobic decomposition of waste in landfills, animal digestion, decomposition of manure, production and distribution of natural gas and oil, coal production and incomplete fuel combustion. It is one of the three main agricultural greenhouse gas (with CO_2 and N_2O).
Microclimate	The climate of a small area resulting from modification of the general climate by local differences in elevation or exposure.
Minimum tillage	Minimum use of tillage necessary to meet crop production requirements under existing soil and climatic conditions, usually resulting in fewer tillage operations than for conventional tillage.
Moldboard plowing	Tillage operation performed to break up soil with partial to complete inversion of soil.
Monoculture	System of crop production that relies on a single crop species in successive years.
Mycorrhizal fungi	Soil fungi that form an association (usually symbiotic) with the roots of host plants, by which energy, water, and nutrient flow between the two organisms. This type of association benefits most agricultural crops substantially.
National Ecological Framework for Canada	Approach devised to provide a consistent, national spatial context within which ecosystems at various levels of generalization can be described, monitored, and reported on. A 1996 report sets out the methodology used to construct ecological framework maps, the hierarchical levels of generalization, descriptions of each ecozone and ecoregion, their linkages to various data sources and examples of applications of the framework.
Native species	Species known to have existed on a site prior to the influence of humans, possibly including long-established exotic species.
Natural enemy scouting	Integrated pest management measure that involves monitoring the levels of natural enemies of a pest in fields.
Natural pasture	*Census of Agriculture* category of agricultural land use denoting uncleared or uncultivated land used for pasture.
Nitrogen	Chemical element in most natural organic substances. Also a key crop nutrient and water pollutant in soluble forms such as nitrate; also forms nitrous oxide.
Nitrous oxide (N_2O)	Potent naturally occurring greenhouse gas whose emissions are enhanced by anthropogenic activities such as nitrogen fertilization, crop residue decomposition and farming of organic soils as well as the deposition, storage and application of manure to agricultural land. It is one of the three main agricultural greenhouse gases (with CO_2 and CH_4).
No-till	Procedure by which a crop is planted directly into the soil using a special planter, with no primary or secondary tillage after harvest of the previous crop.
Nutraceutical	Conventional food product that has been modified (potentially by genetic engineering) to provide improved nutritional characteristics and/or pharmaceutical properties.

Term	Definition
Nutrient	Substance required by a living organism for proper growth and development. Nitrogen, phosphorus and potassium are key crop nutrients.
Offset system	A system that awards credits for verified greenhouse gas emissions reductions or removals by eligible projects.
Overgrazing	Grazing by animals on vegetation at a rate greater than the ability of vegetation to regenerate itself.
Ozone	Naturally occurring gas, formed from normal oxygen. In higher atmosphere, ozone protects the earth by filtering out ultraviolet radiation from the sun.
Particulate matter	Air pollutants composed of minuscule liquid or solid particles temporarily suspended in the atmosphere (e.g. dust, pollen, spores, smoke, organic compounds)
Pasteurization	The process of heating food to kill pathogens such as bacteria, viruses, protozoa, and molds that may be harmful to humans.
Pathogen	A disease-causing agent.
Perennial forage	Grasses and legumes that regrow each spring from the rootstock of plants from the previous growing season.
Permanent cover	Perennial crop that provides vegetative protection to the soil throughout the year. Can be achieved by successive annual or biennial crops in some cases.
Pest	Organism (plant or animal) that is directly or indirectly detrimental to agricultural production.
Pest resistance	A situation in which exposed pests are not affected by a particular recommended application rate of pesticide.
Pesticide	A substance, usually a chemical, that is used to kill or control pests. Pesticides include herbicides, insecticides, fungicides, nematocides, rodenticides and miticides.
pH	An expression of the intensity of the basic or acidic condition of a liquid or of soil generally expressed on a scale ranging from 0 to 14, where values below 7 are acidic, 7 is neutral and values above 7 are considered alkaline.
Phosphorus	Chemical element essential for all living organism and a key crop nutrient. Phosphorus can be the cause of eutrophication above a threshold concentration in fresh water .
Photosynthesis	Process by which plants transform carbon dioxide and water into carbohydrates and other compounds using energy from the sun captured by the plants' chlorophyll.
Phytase	An enzyme common in malt that is widely used in the animal feed industry to increase absorption of organic phosphorus from feed and reduce phosphorus releases to the environment.
Polygon	Irregularly shaped, closed delineation on a map; used in the context of mapping units in the Soil Landscapes of Canada map series and superimposed on Census of Agriculture maps to align soil and landscape data with information on agricultural management practices.
Preferential flow	Process whereby water, soluble substances and compounds such as particulate phosphorus and fecal coliforms move through soil macropores to tile drains and water table.
Pressure-outcome-response framework	Conceptual framework for assessing environmental sustainability that identifies driving forces that influence agricultural activities, outcomes of these activities and responses by society to shape and ensure desirable outcomes.
Pulse crop	Legume that provides edible seeds, such as beans, peas and lentils.
Reduced tillage	Tillage operations that involve less soil disturbance than conventional tillage, either through the use of fewer passes or special equipment. Includes minimum tillage.
Refrigerant	The fluid in a refrigeration system that produce cold by changing from a liquid to a vapour and back to a liquid state at practical pressures.
Return flow	Surface and subsurface water that leaves the field following application of irrigation water.
Riparian area	Land bordering a stream or other body of water.
Riparian buffer strip	Narrow strip of land along a watercourse designed to reduce erosion, intercept pollutants, provide habitat for wildlife and address other environmental concerns.
Rotation	See "crop rotation".
Row cropping	A production system involving crops that are grown in widely spaced rows and that may involve tilling between the rows for weed control, hilling the rows for root protection, or both. Typical row-crops include potatoes, tobacco, vegetables, beans, sugar beets and corn. Usually involves a high level of production per unit area.
Run-off	The portion of precipitation and snowmelt that flows over the land into surface water (e.g. streams, marshes, lakes, etc.).
Salinization	Process by which the content of soluble salts increases at the soil surface or within the root zone.

Term	Definition
Sandy loam soil	Soil material containing sand, clay and silt, with sand particles being predominant, followed by clay particles. For example, a sample consisting of 70% sand and 10% clay falls into the sandy loam soil category.
Sandy soil	Soil material in which sand particles are very abundant.
Semi-arid region	Region with minimum or little precipitation (25 to 50 cm annually). Pertaining to a climate with slightly more precipitation than an arid climate, or to a region in which such a climate prevails and sparse grasses are the characteristic vegetation. Dryland farming methods or irrigation are usually required for crop production in these regions.
Shelterbelt	A barrier of trees, shrubs or other perennial vegetation designed to reduce wind erosion. Also called a windbreak.
Sink	In soils, the capacity to assimilate substances and retain them or subsequently provide them as a source for above- and belowground vegetative growth.
Sludge	The accumulated settled solids separated from various types of water or wastewater as a result of natural or artificial processes.
Smog	Unhealthy air caused by smoke, chemical fumes or dust formed in the atmosphere.
Soil Landscapes of Canada	National series of broad-scale (1:1 million) soil maps containing information about soil properties and landforms.
Soil organic matter	Carbon-containing material in the soil that derives from living organisms.
Soil structure	Physical properties of a soil relating to the arrangements and stability of soil particles, aggregates and pores.
Soil texture	Relative proportion of the different sizes of mineral particles of less than 2 mm (sand, silt and clay) in soil.
Solid residues	All the material inputs to a process that are not turned into products or by-products. This material is either recycled or becomes waste.
Sterilization	The process (mainly by heating) to kill pathogens such as bacteria, viruses, protozoa, molds and heat resistant bacterial spores in food that may be harmful to humans.
Strip cropping	Erosion control method consisting of growing crops that require different types of tillage, such as row crops and permanent grass or annual crops and fallow in alternate strips along contours.
Submetering	Use of separate meters to record the water use of individual unit users while the entire complex of units continues to be metered by the main supplier.
Summerfallow	*Census of Agriculture* category of agricultural land use and general term denoting cropland that is not cropped for at least one year, primarily for the purpose of conserving soil moisture, but is managed by cultivating or spraying to control weeds.
Suspended particulates	Small particles of solid pollutants in sewage that contribute to turbidity.
Sustainable agriculture	An integrated farming system that will, over the long term, satisfy food and fibre needs, enhance environmental quality, make the most efficient use of resources, sustain the economic viability of farm operations and enhance the quality of life.
Tame pasture	*Census of Agriculture* category of agricultural land use denoting pasture that has been improved by management such as cultivation, drainage, irrigation, fertilization, seeding or spraying. Also referred to as "improved pasture" and "seeded pasture".
Taxonomic information	Information about classifying organisms based on how closely related they are.
Terracing	A soil and water conservation technique consisting of a raised level space supported on one or more sides by a wall or a bank.
Trace element	A chemical substance essential to plant or animal life, but required in very small amounts, e.g. less than 1 ppm in plants.
Waterlogging	Situation occurring when soil is fully saturated with water.
Watershed	The area of land from which a waterbody receives water. An area of land that drains water, organic matter, dissolved nutrients and sediments into a lake or stream; the topographic boundary is usually a height of land that marks the dividing line from which surface streams flow in two different directions.
Wetland	Area of land inundated by surface water or groundwater. Under the Canadian Wetland Classification System, wetlands are divided into five classes: bogs, fens, marshes, swamps and shallow waters.
Wildlife	All undomesticated organisms living in the wild, especially animals.
Wildlife habitat	Parts of the natural environment on which an organism depends to carry out its life processes.
Windbreak	A barrier that provides shelter from the wind. Also called a shelterbelt.
Winter cover crop	Crop planted in the fall in order to provide cover and thus curb soil erosion during winter and spring.

Contributing Authors

Rolfe Antonowitsch
AAFC, Prairie Farm Rehabilitation Administration
Regina, Saskatchewan
Email: **antonowitschr@agr.gc.ca**

Yves Arcand
AAFC, Food Research and Development Centre
Saint-Hyacinthe, Quebec
Email: **arcandy@agr.gc.ca**

Shabtai Bittman
AAFC, Pacific Agri-Food Research Centre
Agassiz, British Columbia
Email: **bittmans@agr.gc.ca**

Guy Boivin
AAFC, Horticulture Research and Development Centre
Saint-Jean-sur-Richelieu, Quebec
Email: **boiving@agr.gc.ca**

Lucie Bourque
AAFC, Strategic Policy Branch
Ottawa, Ontario
Email: **bourquel@agr.gc.ca**

Tony Brierley
AAFC, Lacombe Research Centre
Edmonton, Alberta
Email: **brierleyt@agr.gc.ca**

Carolyn Callaghan
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **callaghanc@agr.gc.ca**

Allan J. Cessna
AAFC, Lethbridge Research centre
Lethbridge, Alberta
Email: **cessnaa@agr.gc.ca**

Fulin Chen
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **chenf@agr.gc.ca**

Harvey Clark
AAFC, Strategic Policy Branch
Ottawa, Ontario
Email: **clarkhg@agr.gc.ca**

Dick Coote
Consultant
Stittsville, Ontario
Email: **dcoote@compmore.net**

Farida Dechmi
AAFC, Soils and Crops Research and Development Centre
Sainte-Foy, Quebec
Email: **dechmif@agr.gc.ca**

Reinder De Jong
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **dejongr@agr.gc.ca**

Raymond Desjardins
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **desjardins@agr.gc.ca**

Craig F. Drury
AAFC, Greenhouse and Processing Crops Research Centre
Harrow, Ontario
Email: **druryc@agr.gc.ca**

Grant Edwards
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **edwardsgr@agr.gc.ca**

Robert G. Eilers
AAFC, Cereal Research Centre
Winnipeg, Manitoba
Email: **eilersr@agr.gc.ca**

Warren D. Eilers
AAFC, Saskatoon Research Centre
Saskatoon, Saskatchewan
Email: **eilersw@agr.gc.ca**

Annemieke Farenhorst
University of Manitoba
Winnipeg, Manitoba
Email: **farenhor@ms.umanitoba.ca**

Robert G. Foottit
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **foottitrg@agr.gc.ca**

Catherine A. Fox
AAFC, Greenhouse and Processing Crops Research Centre
Harrow, Ontario
Email: **foxc@agr.gc.ca**

Brian Grant
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **grantbb@agr.gc.ca**

Cynthia A. Grant
AAFC, Brandon Research Center
Brandon, Manitoba
Email: **cgrant@agr.gc.ca**

Julie Grimard
AAFC, Strategic Policy Branch
Ottawa, Ontario
Email: **grimarj@agr.gc.ca**

John Harrington
AAFC, Prairie Farm Rehabilitation Administration
Outlook, Saskatchewan
Email: **harringtonj@agr.gc.ca**

Edward (Ted) Huffman
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **huffmant@agr.gc.ca**

Julian Hutchinson
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **Hutchinsonjj@agr.gc.ca**

Steve K. Javorek
AAFC, Atlantic Food and Horticulture Research Centre
Kentville, Nova Scotia
Email: **javoreks@agr.gc.ca**

Bruce Junkins
AAFC, Strategic Policy Branch
Ottawa, Ontario
Email: **junkibr@agr.gc.ca**

Valerie Kirkwood
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **kirkwoodv@agr.gc.ca**

Maurice Korol
AAFC, Farm Financial Programs Branch
Ottawa, Ontario
Email: **korolma@agr.gc.ca**

Robert Koroluk
AAFC, Strategic Policy Branch
Ottawa, Ontario
Email: **korolur@agr.gc.ca**

David Lapen
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **lapend@agr.gc.ca**

Marie-Line Leclerc
AAFC, Soils and Crops Research and Development Centre
Sainte-Foy, Quebec
Email: **leclercml@agr.gc.ca**

Alexandre Lefebvre
AAFC, Strategic Policy Branch
Ottawa, Ontario
Email: **lefebvrea@agr.gc.ca**

Lavona Liggins
AAFC, Lethbridge Research Centre
Kamloops, British Columbia
Email: **ligginsl@agr.gc.ca**

David Lobb
Soil Science, University of Manitoba
Winnipeg, Manitoba
Email: **lobbda@Ms.UManitoba.CA**

Robert J. Macgregor
AAFC, Strategic Policy Branch
Ottawa, Ontario
Email: **macgrbo@agr.gc.ca**

Michèle Marcotte
AAFC, Food Research and Development Centre
Saint-Hyacinthe, Quebec
Email: **marcottem@agr.gc.ca**

Peter G. Mason
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **masonp@agr.gc.ca**

Abdul Matin
AAFC, Pacific Agri-Food Research Centre
Agassiz, British Columbia
Email: **matina@agr.gc.ca**

Dominique Maxime
AAFC, Food Research and Development Centre
Saint-Hyacinthe, Quebec
Email: **maximed@agr.gc.ca**

Brian McConkey
AAFC, Semiarid Prairie Agricultural Research Centre
Swift Current, Saskatchewan
Email: **mcconkeyb@agr.gc.ca**

Terry McRae
Environment Canada, Watershed Management & Governance Branch
Gatineau, Quebec
Email: **terence.mcrae@ec.gc.ca**

Ross McQueen
University of Manitoba
Winnipeg, Manitoba
Email: **mcqueen@ms.umanitoba.ca**

Owen Olfert
AAFC, Saskatoon Research Centre
Saskatoon, Saskatchewan
Email: **olferto@agr.gc.ca**

Chrystel Olivier
AAFC, Saskatoon Research Centre
Saskatoon, Saskatchewan
Email: **olivierc@agr.gc.ca**

Glenn Padbury
AAFC, Saskatoon Research Centre
Saskatoon, Saskatchewan
Email: **padburyg@agr.gc.ca**

Elizabeth Pattey
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **patteye@agr.gc.ca**

Alain Piau
AAFC, Farm Financial Programs Branch
Ottawa, Ontario
Email: **piaua@agr.gc.ca**

Herb Rees
AAFC, Potato Research Centre
Fredericton, New Brunswick
Email: **reesh@agr.gc.ca**

Keith Reid
Ontario Ministry of Agriculture and Food
Stratford, Ontario
Email: **keith.reid@omaf.gov.on.ca**

Harold Rostad
Consultant
Saskatoon, Saskatchewan
Email: **hrostad@sasktel.net**

Marsha I. Sheppard
Consultant
Pinawa, Manitoba
Email: **sheppardm@ecomatters.com**

Steve C. Sheppard
Consultant
Pinawa, Manitoba
Email: **SheppardS@ECOMatters.com**

Ward Smith
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **smithw@agr.gc.ca**

John C. Tait
Consultant
Pinawa, Manitoba
Email: **Taitj@mts.net**

Georges Thériault
AAFC, Soils and Crops Research and Development Centre
Sainte-Foy, Quebec
Email: **theriaultg@agr.gc.ca**

Don Thompson
AAFC, Lethbridge Research centre
Kamloops, British Columbia
Email: **thompsond@agr.gc.ca**

Laurie C. Tollefson
AAFC, Prairie Farm Rehabilitation Administration
Outlook, Saskatchewan
Email: **tollefsonl@agr.gc.ca**

Ed Topp
AAFC, Southern Crop Protection and Food Research Centre
London, Ontario
Email: **toppe@agr.gc.ca**

Eric van Bochove
AAFC, Soils and Crops Research and Development Centre
Sainte-Foy, Quebec
Email: **vanbochovee@agr.gc.ca**

Laurens J.P. van Vliet
AAFC, Pacific Agri-Food Research Centre
Agassiz, British Columbia
Email: **vanvlietl@agr.gc.ca**

Xavier Vergé
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **vergex@agr.gc.ca**

Suzanne I. Warwick
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **warwicks@agr.gc.ca**

Ted Weins
AAFC, Prairie Farm Rehabilitation Administration
Regina, Saskatchewan
Email: **weinst@agr.gc.ca**

Brian H. Wiebe
University of Manitoba
Winnipeg, Manitoba
Email: **wiebebh@agr.gc.ca**

Devon Worth
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **worthd@agr.gc.ca**

Jingyi Y. Yang
AAFC, Eastern Cereal and Oilseed Research Centre
Ottawa, Ontario
Email: **yangj@agr.gc.ca**

Xueming M. Yang
AAFC, Greenhouse and Processing Crops Research Centre
Harrow, Ontario
Email: **yangx@agr.gc.ca**

Acknowledgments

A report of this scope and complexity would not be possible without the ideas and support of many individuals, groups and organizations. The editors and authors of this report wish to thank the following people and groups for their contributions.

Members of the Steering Committee of the National Agri-Environmental Health Analysis and Reporting Program (NAHARP), who provided the ongoing management support required for program implementation as well as helpful input and advice for various activities, including indicator development. The Steering Committee members are: Alexandre Lefebvre (Chair), Warren Eilers, Bruce Junkins, Bryan Monette, Brook Harker, Peter Schut, and Gordon Murray.

Agriculture and Agri-Food Canada's Environment Team managers and their staff, who were directly involved in all aspects of the work. The following people deserve special mention for their support and leadership: Wayne Lindwall, Rick Butts, Gary Whitfield, Lianne Dwyer, Sherman Nelson and Scott Smith of the Research Branch; Cal Straub and Andrew Cullen of the Prairie Farm Rehabilitation Administration; and Tim Marta and Michelle Brenning of the Strategic Policy Branch. Special thanks also go to the editors (Terence McRae, Scott Smith and Joan Gregorich) and all of the authors and co-authors (too many to list here) of the 2000 AEI report, in recognition of the fact that much of the work highlighted in this report builds on—or is adapted from—that first report.

We wish to thank all those from the farming community, academe, environmental organizations and government, too numerous to mention here, who attended the national workshops on agri-environmental indicators held in December 2001 and March 2002 or participated in the peer and stakeholder reviews of the agri-environmental indicator methods. The workshop discussions and the comments received during the review process were instrumental in guiding the selection and development of suitable indicators for assessing the environmental sustainability of Canadian agriculture. Members of the federal-provincial National Agri-Environmental Co-ordinating Committee and the multi-stakeholder Agri-Environmental Advisory Committee, which were established to support the development and implementation of the Agricultural Policy Framework, provided solid advice on the development and use of the agri-environmental indicators. Kevin Parris, who works for the Organisation for Economic Co-operation and Development, provided a link to related work being done by this agency and by its member countries.

Data processing and mapping services were provided by the Canadian Soil Information System (CanSIS) group at Agriculture and Agri-Food Canada, specifically, Bryan Monette, André Villeneuve, Debbie Pagurek, Derek Brewin, Joanne McGraw and Dave Howlett. Ian Jarvis, Ted Huffman and Ryan Ogston processed the Census of Agriculture enumeration area data for this project.

We are also grateful to all those who participated in the various stages of report preparation. Stéphanie Proux of AAFC handled overall co-ordination. Robin Mackay, Lucie Beaulne, Julie Aughey, Ralph Duchesne and Lorraine Morris provided production support; Régine Voyer, Karine Bazinet, Elaine Boudreault and Jean-Claude Drapeau, of AAFC, helped to co-ordinate translation, as did Edith Président and Danielle Sénécal of the Translation Bureau, Public Works and Government Services Canada (PWGSC); Micheline Pressoir and Julie Sarrazin of the Translation Bureau handled translation; Barbara Chunn, also of the Translation Bureau, handled all the linguistic editing and her colleague, Sylvia McVicar, revised all the references for accuracy. Dave Owens, Laszlo Detre, Glen Sloane and François Magny provided communications support; and Brenda Adams from Accurate Design and Communications Inc. provided design services.

In the section below, the authors acknowledge the contributions that various people made to specific chapters of the report.

Chapter 3: Driving Forces

Portions of this chapter were derived from a similar chapter in the 2000 Report of the Agri-Environmental Indicator Project. Many thanks to Terry McRae for his contributions to that document.

Chapter 5: Linking Science to Policy

Sam Gameda is leading the development of the Land Use Allocation Model (LUAM) which is a key component for future integration of the Agri-Environmental Indicators with policy models.

Chapter 7: Farm Environmental Management Practices

Neil Rothwell and Martin Beaulieu of Statistics Canada provided data and contributed tables from the 2001 Farm Environmental Management Survey.

Chapter 9: Nitrogen Use Efficiency

Con A. Campbell (AAFC) provided helpful suggestions on improving the nitrogen balance methodology, along with references on nitrogen application rates, rotations and tillage practices in the Prairies. K. Bruce MacDonald provided support for the nitrogen balance methodology and Barry Thompson (PEI Department of Agriculture, Fisheries and Aquaculture) provided fertilizer-N rate information for PEI.

Chapter 10: Energy Use Efficiency

Andre Hucq and Chad Wasylyniuk of the University of Saskatchewan provided the 1981-1996 data and the calculation details for the Weseen and Lindenbach (1998) work. Dave Finlayson of the Canadian Fertilizer Institute and Chris Micek of Agrium Inc. helped secure the latest energy coefficients related to fertilizer production. Finally, Ewen Coxworth gave detailed information on energy consumption associated with transportation which was used in deriving final fertilizer-related energy coefficients.

Chapter 11: Water Use Efficiency

Considerable thought went into the development, assessment and selection of the water use indicators. The Water Use Indicator Advisory Committee played an important role in guiding this effort and in preparing the indicator proposal and work plan. Thanks go to all the Committee members: Allan Cessna, Harvey Clark, Robert Eilers, Bruce Junkins, Alexandre Lefevbre, Isabelle Proulx and Dale Tomasiewicz, of AAFC; Russ Boals of Environment Canada (EC); Sietan Chieng of the University of British Columbia; Jean Louis Daigle of the Eastern Canada Soil and Water Conservation Centre; Jean-Marcel Laferriere and Aly Shady of the Canadian International Development Agency; Brent Paterson of Alberta Agriculture, Food and Rural Development; Rebecca Shortt of the Ontario Ministry of Agriculture and Food; Suren Kulshthreshtha of the University of Saskatchewan; and Chandra Madramootoo of the Brace Centre for Water Resources Management, McGill University. Marlene Martinson of AAFC handled arrangements for meetings, conferences and travel.

Chapter 13: Soil Erosion

A) Water Erosion

Thanks are due to the following AAFC staff: Derek Brewin for his invaluable programming support; Ken Webb, Delmar Holmstrom, Jean-Marc Cossette, David Kroetsch, Robert Eilers, Tony Brierley and Elizabeth Kenney for providing data and assisting with data interpretation.

B) Wind Erosion

Paul Krug, consultant, Balcarres, Saskatchewan, provided research assistance. Malcolm Black and Dennis Haak of the Prairie Farm Rehabilitation Administration reviewed the chapter and provided critical comments and editorial suggestions.

C) Tillage Erosion

Guy Mehuys, Dan Pennock and Tom Schumacher, for their participation in this indicator project; Laurens Van Vliet, Derek Brewin and Bryan Monette, for their technical assistance; and Herb Rees, Warren Eilers, Robert Eilers, Tony Brierley, Alexandre Lefebvre and Scott Smith, for their support.

Chapter 15: Soil Salinity

Glenn Lelyk (AAFC) provided valuable GIS and data analysis support for this chapter. Tom Goddard and Frank Hecker (Alberta Agriculture), Peter Haluschak and Glen Podolsky (Manitoba Agriculture), and Harold Steppuhn (AAFC) provided useful comments on the updated salinity map used to calculate the indicator.

Chapter 17: Nitrogen

Sam Gameda (AAFC) provided the daily ecodistrict climate database.

Chapter 18: Phosphorus

K. Bruce MacDonald, Martin Bolinder and Suzanne Beauchemin provided technical information for the first version of this indicator. Jean-Marc Cossette assisted with GIS data processing. Luc Lamontagne and Michel Nolin contributed their expertise in pedology to the pairing of soil attributes with the GIS database. Yves Lefebvre and Richard Beaulieu of Quebec's Ministère du Développement durable, de l'Environnement et des Parcs and Martin Bolinder, Luc Lamontagne and Jean-Marc Cossette of AAFC, commented on a preliminary version of this chapter. Nadia Goussard participated in the indicator development process and provided suggestions for future enhancement.

Chapter 19: Pesticides

The participants in the March 2004 IROWC-Pest workshop played an instrumental role in developing the approach used in this indicator. They were: Reinder DeJong, Robert Eilers, Warren Eilers, Colleen Hyslop, Alexandre Lefebvre, Elizabeth Pattey, Georges Thériault Eric Van Bochove and Tom Wolf (AAFC); Clair Murphy and Jane Elliot (Environment Canada); Jacques Drolet and Regi Mathew (Pest Management Regulatory Agency); Esther Salvano (University of Manitoba); Suzanne Allaire (Université Laval); and K. Bruce Murray (Manitoba Agriculture and Food).

Chapter 21: Greenhouse Gases

Many colleagues across Canada assisted in the calculation of greenhouse gas emissions. We would especially like to acknowledge Chang Liang of Environment Canada for his valuable comments, as well as the AAFC Model Farm and NCGAVS (National Soil Carbon and Greenhouse Gas Accounting and Verification System) teams, for their ongoing efforts to develop and improve the national and regional emission factors. Financial assistance was received from the Panel on Energy Research and Development of Natural Resources Canada.

Chapter 22: Ammonia

The authors would like to thank Sven G. Sommer, of the Danish Institute of Agricultural Sciences, for his valuable assistance and Jim Webb, ADAS, Wolverhampton, UK, for providing the NARSES model.

Chapter 23: Particulate Matter

Tanya Bradley of Masterloy Products, Ottawa, Ontario co-authored the scoping report on particulate matter.

Chapter 24: Wildlife Habitat on Farmland

We appreciate the contributions of Erin and Peter Neave (Neave Resource Management) to the development and enhancement of the Wildlife Habitat Capacity Indicator. Lisa Toulen (Environment Canada) provided valuable species distribution data. Helpful reviews and comments were provided by Cathy Neilsen (Ontario Ministry of Natural Resources), Alain Baril and Carolyn O'Neill (Environment Canada), George Hamilton, Chris Shank, Dave Prescott, Harry Stelfox, Terry Kosinski John Tackaberry (Alberta Sustainable Resource Development), Amanda Manuel (Keystone Agriculture Producers), Karla Guyn (Ducks Unlimited Canada) and Michael Watmough (Environment Canada).

We also extend our thanks to the following people for their valuable input: Troy Riche, Lawrence Townley-Smith, Ute Holweger, Jamie Hewitt, Lori Heigh, Doug Chekay, Heather Wiebe, Catherine Fox and Guy Baillargeon (AAFC); Brenda Dale, Benoit Jobin, Risa Smith and Michele Williamson (Environment Canada); Lyle Boychuk, Ken Lumbis and Gregg Brewster (Ducks Unlimited Canada); Randy Milton (Nova Scotia Department of Natural Resources); Lowell Strauss (Nature Conservancy of Canada); and Ed Wiken (Wildlife Habitat Canada).

Chapter 25: Wildlife Damage to Crops and Livestock

We appreciate the contributions of Lucie Bourque, Lori Heigh, J. Andrea Tanaka, Bob Vernon and Ian Campbell (AAFC), along with William McBride (private consultant) and Michele Williamson (Environment Canada) to the development of the Wildlife Damage Indicator. Valuable reviews and comments were provided by Cathy Neilsen (Ontario Ministry of Natural Resources), Ken Belcher (University of Saskatchewan), Mike Gollop (Saskatchewan Environment), Pat Rakowski (Environment Canada), Pierre Brousseau (Environment Canada), Pamela Martin (Environment Canada), Amanda Manuel (Keystone Agriculture Producers), Michael Langman (Nova Scotia Agriculture and Fisheries), to Hugh Berges (Ontario Ministry of Agriculture and Food) and Gary Coghill (Saskatchewan Agriculture, Food and Rural Revitalization). We also wish to thank the following people for their participation in the 2004 wildlife damage workshop: C. Cormack Gates (University of Calgary) and Glen Parson (Nova Scotia Department of Natural Resources).

Chapter 27: Soil Biodiversity

Thanks are due for the valuable contributions of the Soil Biodiversity Indicator team members (Ian Jarvis, Valérie Behan-Pelletier, Yolande Dalpé, Jill Clapperton, Danielle Prévost, David Lapen (AAFC); along with Monika Joschko, Peter Lentzsch and Marion Tauschke (Leibniz-Centre for Agricultural Landscape and Land Use Research, [ZALF], Müncheberg, Germany) to the development of the conceptual framework. Special thanks go to Ian Jarvis, Germarie Balactico, Thierry Fisette, Pierre-Yves Gasser, Bahram Daneshfar and Greg Gibbons (AAFC REIS team, Ottawa) for GIS support for the proof-of-concept model.

Chapter 28, 29 and 30: Food and Beverage Industry

The authors are also very grateful to Glenda Taylor and Jessica Norup (Office of Energy Efficiency, Natural Resources Canada), along with Mihaela Andronescu (Environment Canada), for their valuable assistance in reviewing the project proposal and several manuscripts and questionnaires. The authors gratefully acknowledge the advice provided by Bruno Pépin (Statistics Canada), Nathalie Trudeau (Office of Energy Efficiency, Natural Resources Canada) and John Nyboer (Canadian Industrial Energy End-use Data and Analysis Centre, Energy and Materials Research Group) for the development of the energy and GHG indicators and for improving the text content and format through their comments and proofreading work. The authors extend their thanks to Sophie Taillefer (Recyc-Québec) for providing published data and for helping to write the manuscript on the organic solid residues and packaging indicators. Thanks are also extended to Martin Lemire (Natural Resources and Waste Accounts, Statistics Canada) and Michel Villeneuve (Sustainable Water Use Branch, Environment Canada) for their valuable input on the water and wastewater indicators. Finally, the authors are very grateful for advice and comments received throughout the project from representatives of selected food and beverage companies.

Notes

Notes